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Ecological Impact of Integrated Chemical and Biological Aquatic Weed Control

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This final report presents results of a four-year study of the ecological impacts of chemical, biological, and integrated methods of aquatic weed control. Biological and water quality changes occurred as abundance of macrophytic vegetation was altered by natural factors or management practices. Macrophyte abundance strongly influenced the structure of communities, and it was concluded that environmental effects of plant management programs are determined more by the amount of vegetation controlled than by management technique. Also, changes in lake hydrology and rates of nutrient loading appear to be more important as determinants of lake water quality than macrophytes. Research needs for evaluation of effects of weed control on aquatic systems are identified.

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ECOLOGICAL IMPACT OF INTEGRATED CHEMICAL AND BIOLOGICAL AQUATIC WEED CONTROL

by

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CONTENTS

Page

Foreword v

Introduction. 1
  Study Area 3
    Lake Pearl. 3
    Orange Lake 6
    Welaka Ponds. 8
Methods 10
  Sampling Stations. 10
    Lake Pearl. 10
    Orange Lake 10
  Vegetation 13
  Phytoplankton. 14
  Water Quality. 17
  Periphyton 18
  Benthos. 19
  Zooplankton. 19
  Fish 20
    Blocknets 20
    Electrofishing. 21
    Telementry. 22
Results and Discussion. 23
  Vegetation 23
    Lake Pearl. 23
    Orange Lake 33
    Welaka Ponds. 41
      Grass carp ponds 46
      Herbicide ponds. 54
  Water Quality. 63
    Lake Pearl. 63
    Orange Pearl. 89
    Welaka Ponds. 115
      Diel chemistry values. 135
  Phytoplankton. 147
    Lake Pearl. 147
    Orange Lake 150
    Welaka Ponds. 154
  Periphyton 166
    Lake Pearl. 166
  Aquatic Invertebrates. 170
    Lake Pearl. 170
    Orange Lake 183
    Welaka Ponds. 193

- Fish .213
  - Blocknets Lake Pearl .213
  - Orange Lake .220
    - Juvenile sportfish .222
    - Harvestable Sportfish .224
      - Fish habitat relationships .227
    - Welaka Fish .235
    - Food Habits .238
      - Lake Pearl .238
      - Orange Lake .246
    - Coefficient of Conditions .262
      - Lake Pearl .262
      - Orange Lake .269
    - Telemetry .281
      - Lake Pearl .281
    - Bass Spawning .286
      - Lake Pearl .286
    - Bass Growth and Population Estimate .291
      - Lake Pearl .291
    - Creel Data .302
      - Orange Lake .302
- Conclusions .307
- Research Recommendations .311
- Literature Cited .314

FOREWORD

The protection of our aquatic areas from damage caused by toxic organic pollutants requires that regulations restricting the introduction of these compounds into the environment be formulated on a sound scientific basis. Accurate information describing dose-response relationships for organisms and ecosystems under varying conditions is required. The EPA Environmental Research Laboratory, Gulf Breeze, contributes to this information through research programs aimed at determining:

- the effects of toxic organic pollutants on individual species and communities of organisms;
- the effects of toxic organics on ecosystem processes and components;
- the significance of chemical carcinogens in the estuarine and marine environments.

Undesirable effects of herbicides applied for control of aquatic weeds may be minimized by concomitant use of herbivorous fishes which consume the target weed species. Lower concentrations of chemical herbicides may be used in integrated control programs than in non-integrated programs. This report describes studies on integrated use of herbicides and the grass carp and their possible ecological effects in weed control programs. Data on efficiency of control and effects upon ecosystem function are useful to the U.S. Environmental Protection Agency for development of strategies that will minimize the harmful impact of toxic substances on the environment.

Henry F. Enos

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INTRODUCTION

Aquatic weed infestations in lakes of the United States and other countries have increased dramatically during the last several decades because of cultural eutrophication and the introduction of exotic plants such as hydrilla (_Hydrilla verticillata_) and eurasian watermilfoil (_Myriophyllum spicatum_). Because these weed infestations have severely restricted many domestic, agricultural, industrial, and recreational water uses, there have been increased demands for weed control. Water however, is becoming an increasingly valuable resource and many user groups are now expressing concern about the impact of aquatic plant control techniques on the aquatic environment. Because of this concern, there have been increased demands for the development of effective, yet environmentally safe, aquatic plant management programs.

Formulation of aquatic plant management programs for different aquatic systems, however, is extremely difficult. Many scientists believe aquatic plants are important for healthy fish and wildlife populations and for proper functioning of aquatic ecosystems (cf. Wetzel 1975), but there is little quantitative data available for determining how many plants are necessary. It is also often very difficult to obtain an accurate assessment of what level of aquatic plant abundance constitutes a weed problem. There are difficulties involved with assessing what the short-term and long-term economic, sociological, and environmental impact of different control techniques may be. For example, aquatic herbicides are presently used by many local, state, and federal agencies to control aquatic macrophytes. Although all herbicides are tested and eventually registered for use by the U.S. Environmental Protection Agency, some agencies and some segments of the public do not believe that the long-term impacts of chemical control are sufficiently known to justify the use of herbicides. Many aquatic herbicides are also not effective for long periods of time;

therefore, considerable amounts of money must be expended each year for control. Florida alone spends over 9 million dollars annually. Grass carp (Ctenopharyngodon idella) are an effective, economic, biological control organism (Shireman, 1982), but the fish consume all macrophytic vegetation when stocked in sufficient numbers. Because research studies on grass carp have provided conflicting and often confusing results, biologists cannot agree as to the fish's ultimate impact on the aquatic environment. This has led to the banning of the use of grass carp in many areas including Florida. Because fresh waters are used for a variety of purposes, the costs and benefits to various user groups must also be considered. In Florida, freshwater sportfishing is a very large aquabusiness generating over 525 million dollars annually (Bell 1979). However, the major value of water in Florida is derived from the aesthetics of living near water and the resultant increased land values. While fishermen generally want vegetation, homeowners generally want weed-free shorelines and quite often weed-free lakes. Because of different desires, these groups are often in direct conflict.

This study was initiated to provide quantitative information on the influence of various levels of aquatic plants and the impact of chemical and biological (grass carp) management techniques on the aquatic environment. The study consisted of 3 separate projects. Orange Lake, a large lake with an abundance of macrophytes, was studied to determine what the effect of naturally occurring fluctuations in vegetation are and what effect different vegetation types may have on the aquatic environment. Lake Pearl, a small lake with an abundance of hydrilla was studied to determine if chemical and biological control techniques could be integrated to provide long-term vegetation management without removing all vegetation. The impact of integrated management on the aquatic environment was also studied. Finally, pond studies were conducted to determine the environmental impact of different aquatic plant management techniques at different levels of weed management.

STUDY AREAS

Lake Pearl

Lake Pearl is a 23.5 ha eutrophic lake in Orange County, Florida (Figure 1). The lake receives surface runoff from a marsh located to the east and discharges water into Lake Burkett via a drainage ditch which is located on the north shore. Prior to grass carp introduction, fish confinement barriers were constructed at inflow and outflow sites. The lake has a maximum depth of 7.0 m (sinkhole in west end) and a mean depth of 2.5 m. These parameters, however, were affected by fluctuating water levels during this study (Table 1). Submersed vegetation was dominated by hydrilla which first appeared in 1977. By 1978, coverage exceeded 95% of the lake during periods of peak infestation. This high level of infestation continued until 1981 when grass carp eliminated hydrilla and other submersed vegetation. Other submerged vegetation included: bladderwort (_Utricularia_ sp.), southern naiad (_Najas guadalupensis_), and watermilfoil (_Myriophyllum heterophyllum_). Coverage of these native plants did not exceed 10%. The floating leafed plants, spatterdock (_Nuphar luteum_) and fragrant water lily (_Nymphaea_ _odorata_) covered 10% of the lake's surface area, with most coverage occurring adjacent to the marsh in the cove at the eastern end of the lake. At the beginning of the study, the lake was fringed by a 12 m band of nut rush (_Scleria_ sp.). However, when lake water level decreased in 1981, the nut rush band was replaced by a mixed shoreline vegetation community. Stands of cattail (_Typha_ _latifolia_), arrowhead (_Sagittaria lancifolia_ and _rotundifolia_), pickerelweed (_Pontederia lanceolata_), torpedograss (_Panicum_ _repens_) and water pennywort (_Hydrocotyle_ _umbellata_) became established. At study initiation, urban development of the lake was less than 20%. By 1982, development had increased to greater

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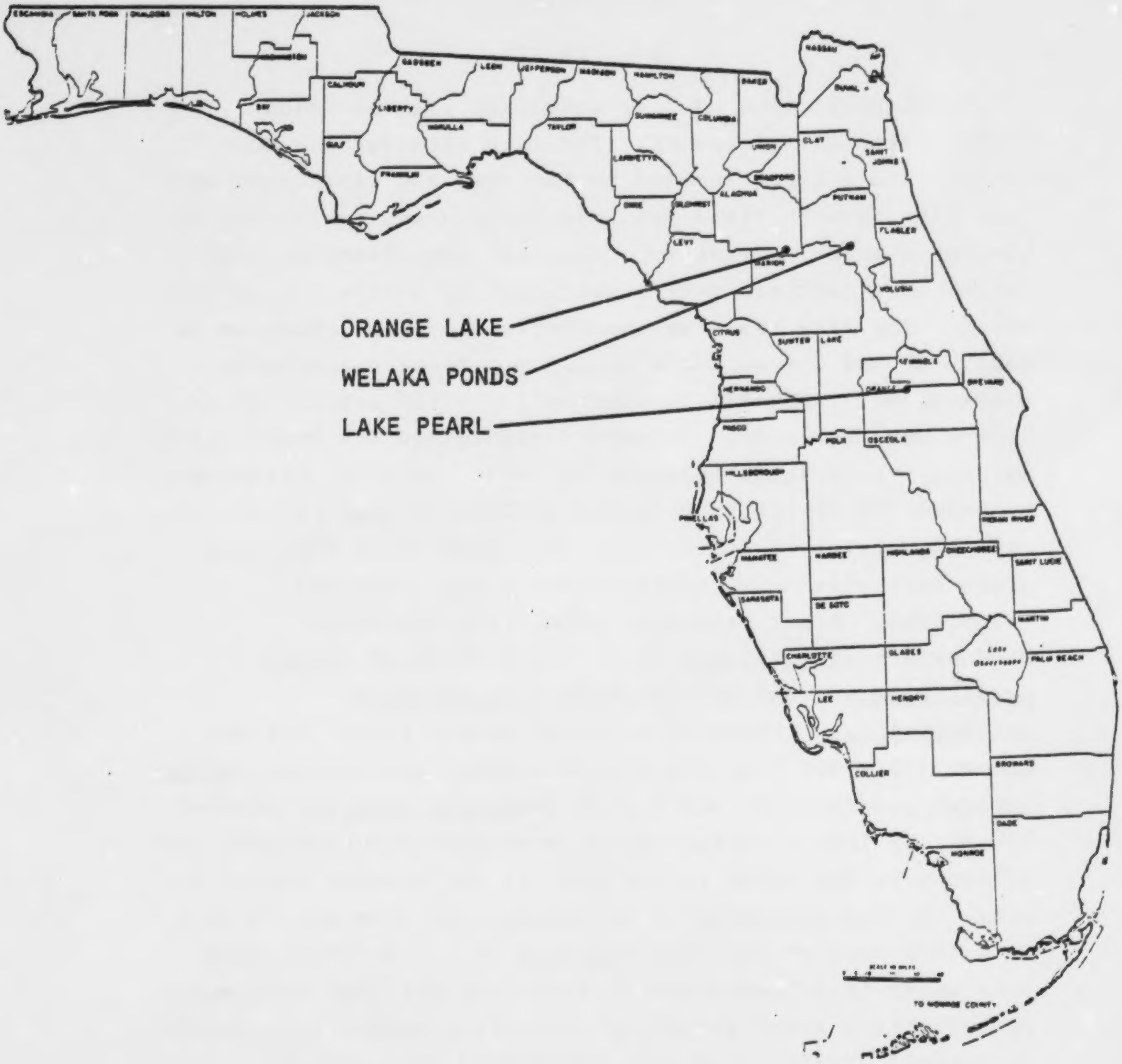
ORANGE LAKE
WELAKA PONDS
LAKE PEARL
ESCAMBIA
SANTA ROSA
OKALOOSA
WALTON
HOLMES
JACKSON
WASHINGTON
CALHOUN
BAY
GULF
LIBERTY
GADSDEN
LEON
JEFFERSON
MADISON
HAMILTON
WAKULLA
FRANKLIN
TAYLOR
SUWANNEE
COLUMBIA
BAKER
NASSAU
DUVAL
UNION
CLAY
SAINT JOHNS
BRADFORD
LAFAYETTE
GILCHRIST
ALACHUA
PUTNAM
DIXIE
LEVY
MARION
FLAGLER
VOLUSIA
CITRUS
SUMTER
LAKE
SEMINOLE
HERNANDO
ORANGE
BREVARD
PASCO
POLK
OSCEOLA
HILLSBOROUGH
PINELLAS
INDIAN RIVER
MANATEE
HARDEE
HIGHLANDS
OKEECHOBEE
SAINT LUCIE
SARASOTA
DE SOTO
MARTIN
CHARLOTTE
GLADES
Lake Okeechobee
PALM BEACH
LEE
HENDRY
COLLIER
BROWARD
DADE
MONROE
SCALE IN MILES
TO MONROE COUNTY

Figure 1. Location of Lake Pearl, Orange Lake and Welaka Ponds.

Table 1. Lake Pearl elevation (m), 1979-1982.

	1979	1980	1981	1982
January				15.4
February			15.7	15.2
March		16.2	15.6	15.1
April	16.5	16.2	15.4	15.3
May			15.2	15.3
June		16.2		
July			15.0	15.5
August		16.0	14.9	15.9
September			15.0	
October		15.9		15.4
November			15.0	
December		15.8	15.0	15.9

than 60% and the majority of lakefront lot owners had all emergent vegetation removed from their property.

Orange Lake

Orange Lake, a 4900 ha eutrophic lake, is located in Marion and Alachua counties, Florida (Figure 1).

Orange Lake receives water from Newnan's and Lochloosa lakes through the River Styx and Cross Creek. Together, these lakes have a drainage basin of approximately 968 square km. Water leaves Orange Lake through Orange Creek which is a small tributary of the Ocklawaha River. At full stage, maximum depth in Orange Lake is 4.9 m, average depth 2.9 m development of shoreline 2. Water level, however, fluctuates considerably among years causing increases or decreases in the surface area (Table 2). For example, water level fluctuated 1.7 m from a low in December, 1977 to a high in September 1978. The lake bottom is composed primarily of muck which averages 1.0 m in depth. The lake has considerable fetch on windy days, which causes mixing of bottom sediments in the water column. Dense stands of vegetation are prevalent within the lake. Spatterdock is very extensive in the southwestern and eastern shore areas. Maidencane (*Panicum hemitomon* and *P. geminatum*), coontail (*Ceratophyllum demersum*), pickerelweed (*Pontederia lanceolata*), arrowhead (*Sagittaria* sp.), fanwort (*Cabomba caroliniana*) and bladderwort are also abundant. Historically, the spatterdock and coontail plant communities were the dominant, covering approximately 50% of the lake surface. Hydrilla was first reported in Orange Lake in 1974 when the estimated coverage was 20 ha (Krummrich 1979). Coverage increased to 109 ha in 1975 and by 1976 total lake coverage exceeded 3900 ha. Maximum coverage was attained in 1976 and 1977. A substantial decline occurred in 1978. Prior to 1976 and during 1978 and 1979, the spatterdock and maidencane communities were virtually hydrilla-free. During all other study years, hydrilla coverage was in excess of 80% within these communities.

Table 2. Water surface area for Orange Lake, 1974-1982.

Date	Surface Area Ha
Spring 1974	4490
Fall 1977	3080
Spring 1978	4780
Fall 1978	4620
Spring 1979	4780
Fall 1979	4780
Spring 1982	4780

Since 1975, hydrilla control programs have been implemented in Orange Lake by various state and federal agencies. Even though control measures were implemented, hydrilla coverage in the historical open water area of the lake increased to 59% in 1977. Because surface mats hindered all boat traffic, both chemical and mechanical control operations during 1976 and 1977 were directed toward maintenance of boat trails and access points within the lake. High water during Winter 1977 - 1978, coupled with phytoplankton blooms during Spring 1978, caused the hydrilla to decline. Continual encroachment by hydrilla into open water areas has occurred since 1978.

Welaka Ponds

Twenty-four, square, 0.2 ha ponds (average depth 1.5 m) located at Welaka, Florida (Figure 1) were utilized to determine the environmental effects of chemical, biological and mechanical control methods (Figure 2). These ponds were drained and excavated prior to the start of the experiment to remove all vegetation. Water was supplied to the ponds from a deep well as needed. Hydrilla was planted in 21 of the ponds during 1978 and sportfish (bluegills, Lepomis macrochirus and largemouth bass, (Micropterus salmoides) were stocked into all ponds during 1978-1979. During Summer 1981, pump failure coupled with drought conditions, resulted in the loss of three experimental ponds. Because the ponds represented different treatments, the overall experimental design was not compromised.

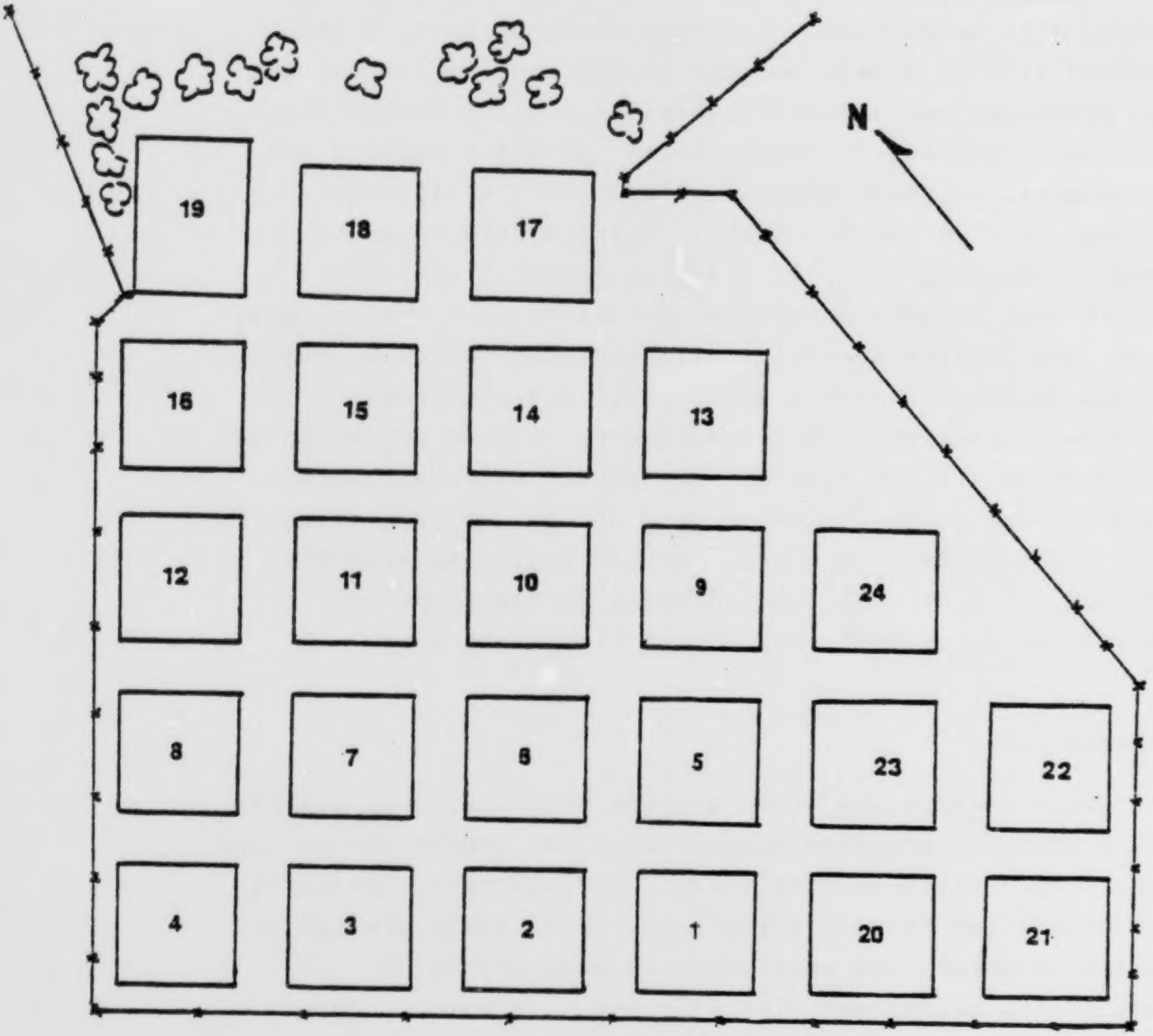
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Figure 2. Schematic drawing of Welaka ponds, Welaka, Florida.

METHODS

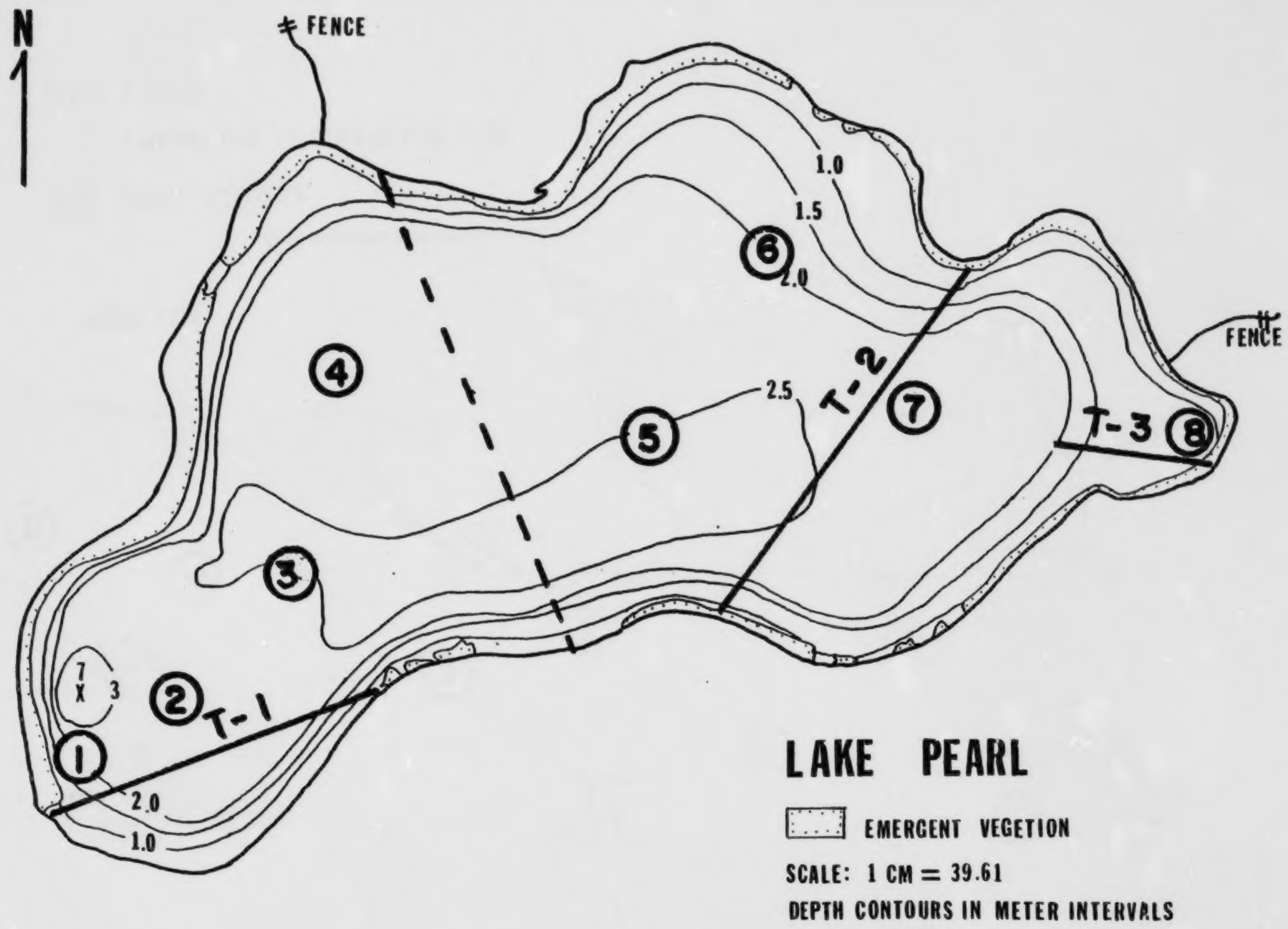
Sampling Stations

Lake Pearl

Eight stations were sampled monthly in Lake Pearl (Figure 3). Limnetic stations 2, 3, 4 and littoral station 1 were located in the western half of the lake which was treated with herbicides. Limnetic stations 5, 6, 7 and littoral station 8 were located in the eastern half of the lake which was not treated chemically. Six limnetic sites (stations 2 through 7) were sampled for water quality and phytoplankton. Zooplankton were collected at limnetic stations 2, 3, 5 and 7. Benthic sampling was conducted at limnetic stations 2, 3, 5, 7 and at littoral stations 1 and 8. Littoral benthic station 8 is located in a shallow cove in an area heavily vegetated with floating leafed plants (spatterdock and fragrant water lily) and submersed vegetation (hydrilla and bladderwort). Bottom sediments at this station are 80% sand and 20% muck. Littoral benthic station 1 was on the lakeward edge of the nut rush fringe along the northwestern shore. Bottom sediments were 50% sand and 50% muck. Bottom sediments of all limnetic stations were composed entirely of flocculent muck.

Orange Lake

Water quality and algal samples were collected monthly from 5 limnetic stations transversing the length of the lake (Figure 4). Benthic, zooplankton, and blocknet collections were stratified by vegetation type. Triplicate samples of all biotic parameters were taken in pure stands of spatterdock, maidencane, hydrilla and open water. Bottom sediments by vegetation type were: Spatterdock, (50% vegetational detritus - 50% muck); maidencane (80% vegetational detritus - 20% muck); hydrilla, (50% vegetational detritus - 50% muck); and open water (10% vegetational detritus - 90% muck).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FENCE
FENCE
1.0
1.5
2.0
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2.0
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7
X
3
1
2
3
4
5
6
7
8
T-1
T-2
T-3
LAKE PEARL
EMERGENT VEGETION
SCALE: 1 CM = 39.61
DEPTH CONTOURS IN METER INTERVALS

Figure 3. Sample stations (O) and line transect (T-) locations in Lake Pearl, Florida.

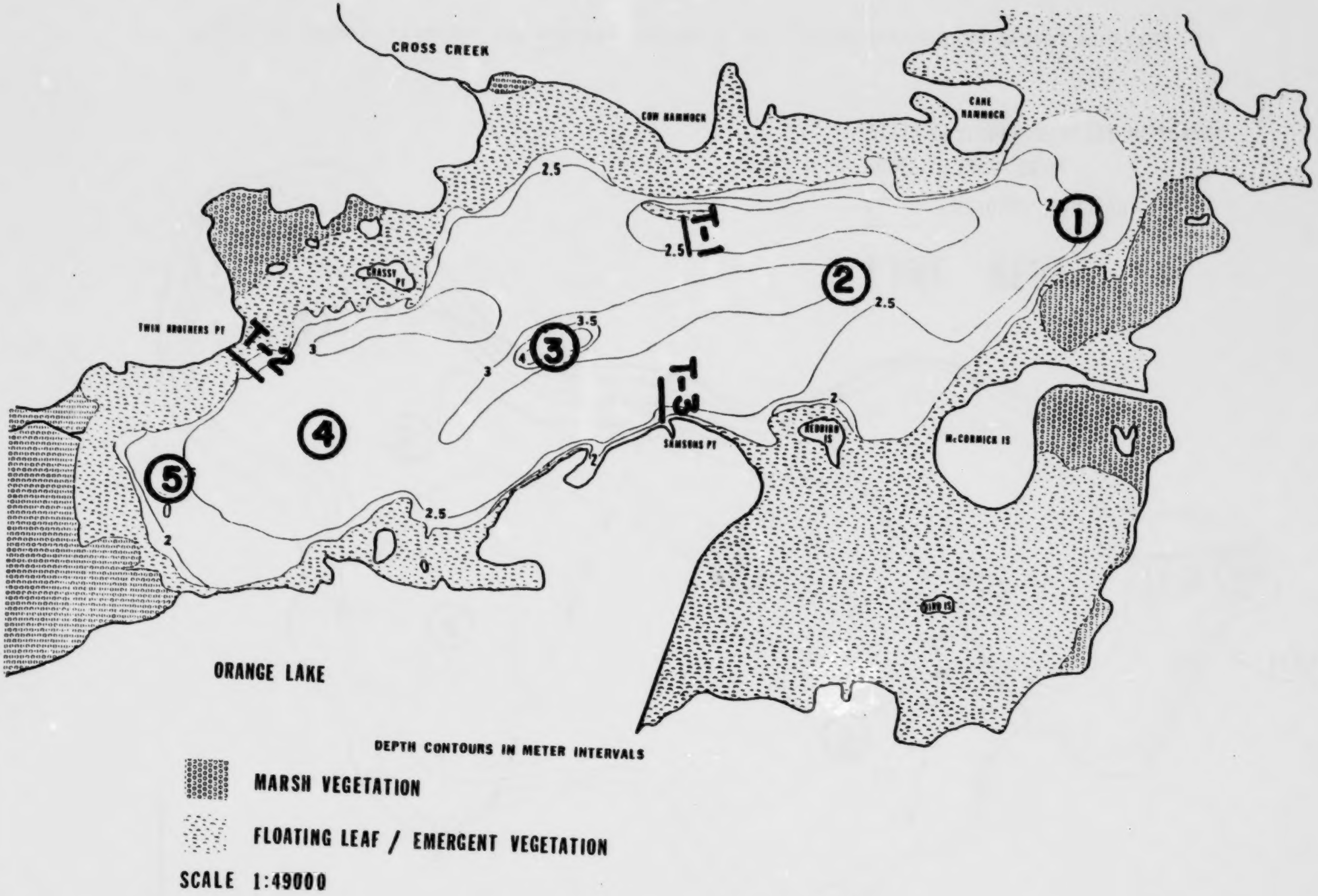

CROSS CREEK
COW HAMMOCK
CANE HAMMOCK
GRASSY PT
TWIN BROTHERS PT
SAMSONS PT
REDDING IS
McCORMICK IS
BIRD IS
ORANGE LAKE
T-1
T-2
T-3
1
2
3
4
5
0
2
2.5
3
3.5
4
DEPTH CONTOURS IN METER INTERVALS
MARSH VEGETATION
FLOATING LEAF / EMERGENT VEGETATION
SCALE 1:49000

Figure 4. Sample locations (O) and line transect (T-) locations in Orange Lake, Florida.

Vegetation

To determine percent frequency of occurrence and percent relative cover of aquatic vegetation, modified line transects using points and plots were run monthly on Lake Pearl, Orange Lake and in each of the 24 study ponds at Welaka until vegetation relationships were established. Quarterly samples were taken thereafter. Three transect sites were selected within Lake Pearl to insure a representative selection of the vegetation within the lake (Figure 3). Line 1 was placed through a portion of the lake treated with herbicides, and line 2 was placed, through a portion of the lake stocked with grass carp. Line 3 was through a spatterdock and fragrant water lily community. Permanent shore markers were established for lines 1 and 2. A permanent shallow water marker was established for line 3 and secured by a floating buoy at the end of the transect. Three transect sites were selected for Orange Lake. Line 1 was in deep water maidencane beds near Cow Hammock (x depth 2.8 m) and line 2 was a shore to deep water transect off Twenty Brothers Point representing the littoral vegetation community (x depth 1.9). Line 3 was a shore to deep water transect of littoral maidencane and open water (x depth 3.2 m) located at Sampson's Point. A permanent marker was established in deep water on line 1 and secured by a floating buoy at the end of the transect. Lines 2 and 3 were secured by permanent markers on shore and floating buoys in open water. At the Welaka ponds, 1 transect was run diagonally across each pond. Along each transect line, a frotus was lowered into the water at 2 m intervals and plants touching the frotus were recorded, as was water depth and plant height. The percent cover of each plant species was estimated at 10 m intervals within a 1 meter square. Annual estimation of total aquatic macrophyte coverage was conducted in each Welaka pond.

Total hydrilla biomass was estimated in Lake Pearl with a 0.257 m^2 circular biomass sampler (Nall and Schardt 1978).

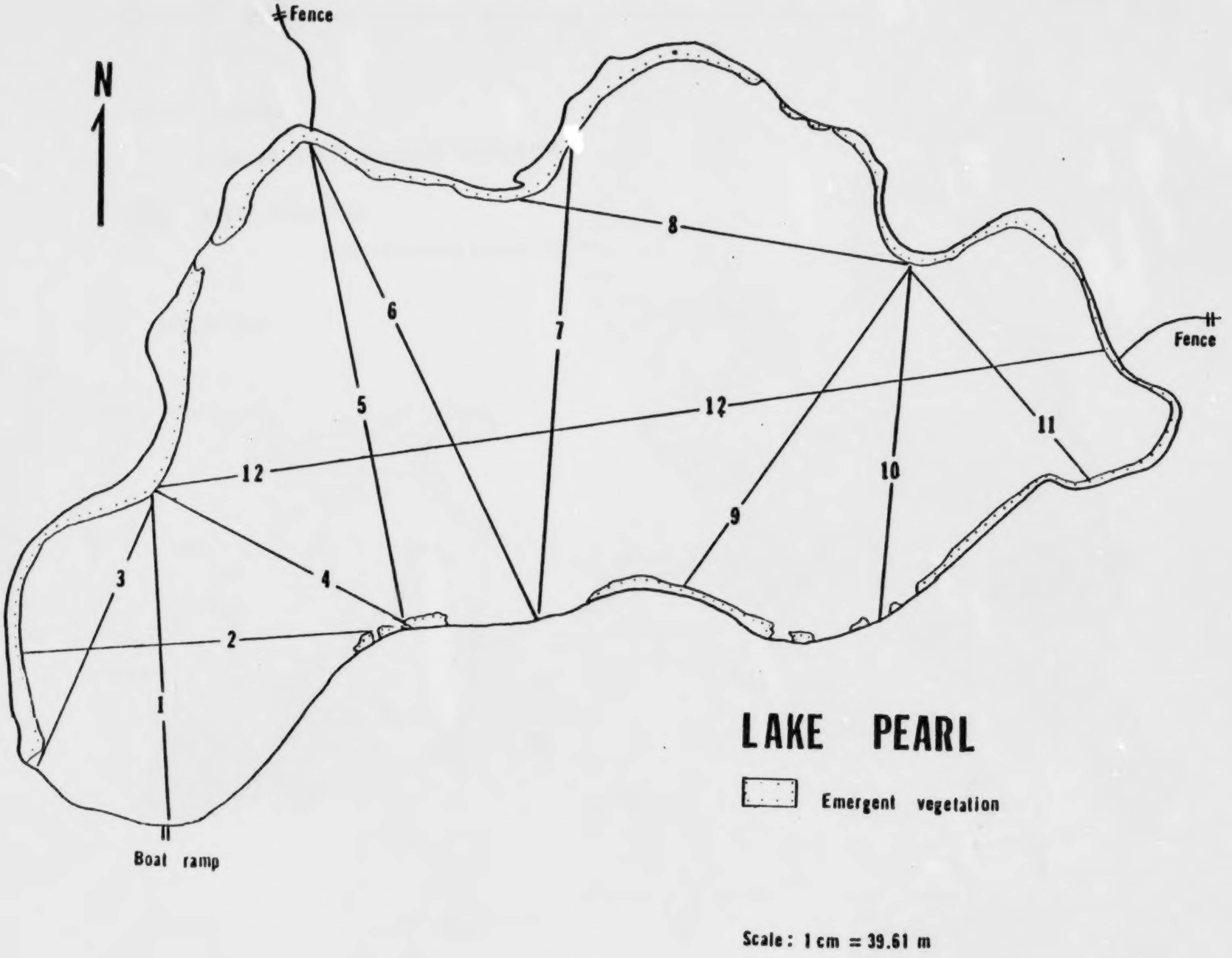
Twenty-five stations were randomly chosen from areas having submersed vegetation. Replicate samples were collected at each station. Vegetation samples were washed and shaken in a nylon net to remove sand, muck and water. Samples were weighed to the nearest 5 g and converted to kg/m^2 for biomass estimation.

At Lake Pearl and Orange Lake, a DE-719 Precision Survey Fathometer (Raytheon Marine Co., Manchester, New Hampshire) was utilized to construct bathymetric maps and monitor hydrilla distribution. Procedures for conducting transects and quantitative vegetation determinations were those described by Maceina and Shireman (1980). In Lake Pearl, 12 submersed vegetation transects, totaling 3.44 km, were established (Figure 5). Thirteen transects totaling 28.7 km were established at Orange Lake (Figure 6).

Phytoplankton

Two, 200 ml samples were taken with a 2-liter Van Dorn bottle at a depth of 0.3 m at each algal sampling station. Within 72 hrs, algae were prepared for identification. A 40 ml aliquot of the sample was centrifuged for 5 min at 1840 X G. The supernate was poured off, and more water from the sample added and centrifuged, until the entire 200 ml sample was reduced to a 5 ml concentrate. Algae were then resuspended and preserved in 10 ml of a solution which was prepared by mixing 3-4 ml of 40% formaldehyde, 5 ml of a 20% solution of clear detergent, and 5-8 drops of a saturated cupric sulfate solution and bringing it to 100 ml with distilled water.

For quantitative and qualitative analysis, a 0.1 ml sample was removed from the 15 ml concentrate and placed in a Palmer Counting Cell. Organisms in 20 randomly selected fields were counted using a phase contrast microscope (430X), and the average number of each type of phytoplankton per field determined. This was expanded to number/liter utilizing the following conversion factor: $N = 15/200(A)(1 \times$


N
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Fence
Boat ramp
1
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4
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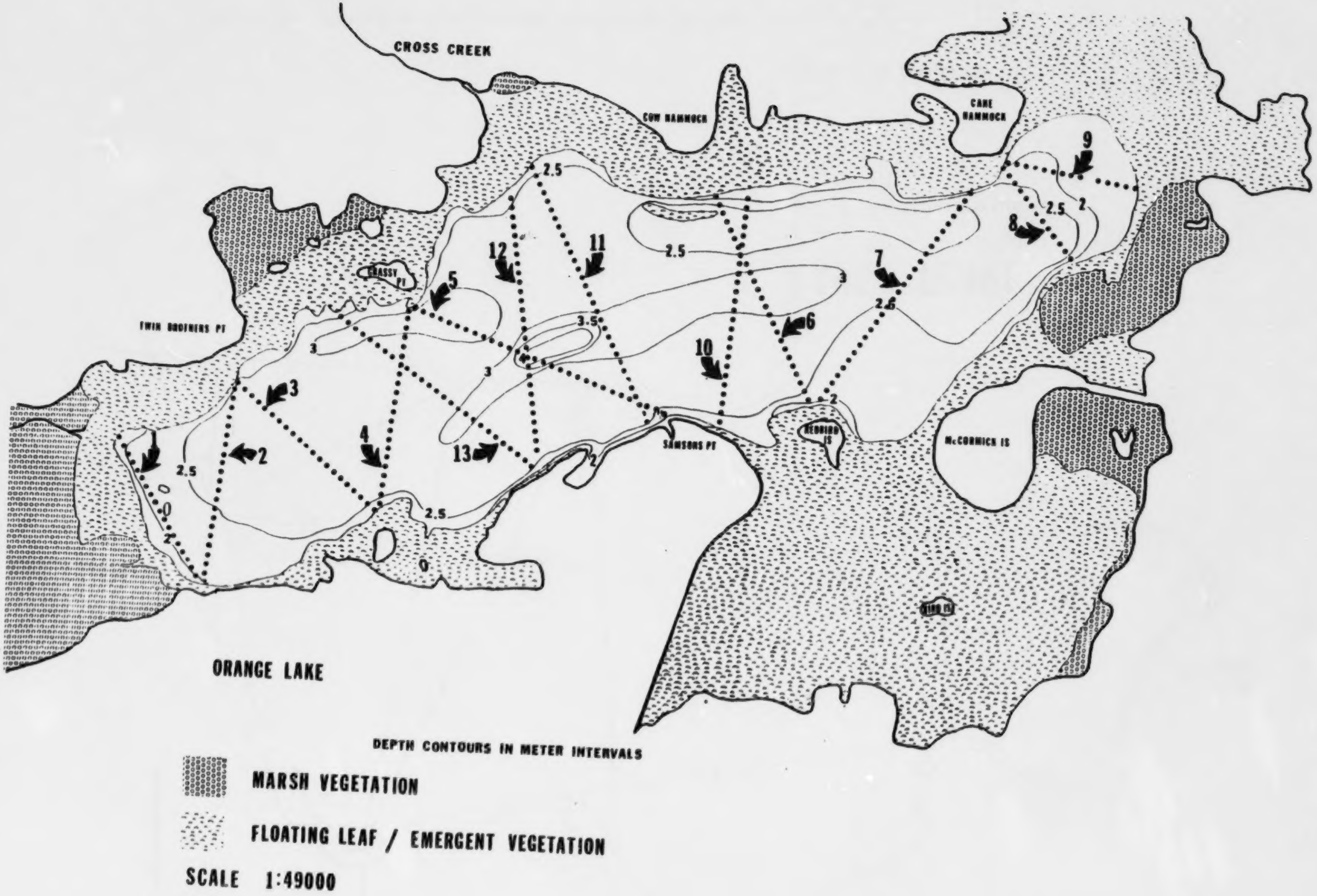
10
11
12
12
LAKE PEARL
Emergent vegetation
Scale: 1 cm = 39.61 m

Figure 5. Fathometer transects conducted in Lake Pearl, Florida.


CROSS CREEK
COW HAMMOCK
CANE HAMMOCK
TWIN BROTHERS PT
GRASSY PT
SAMSONS PT
REDBIRD IS
McCORMICK IS
BIRD IS
ORANGE LAKE
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11
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13
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2
2.5
2.6
3
3.5
DEPTH CONTOURS IN METER INTERVALS
MARSH VEGETATION
FLOATING LEAF / EMERGENT VEGETATION
SCALE 1:49000

Figure 6. Fathometer transects conducted in Orange Lake, Florida.

10^6)/(3.14) (0.215^2)(0.4); where N = number/liter, 15/200 = concentration factor for concentrated samples, A = average number of cells/field for each genus at 430X for 20 fields, 1 x 10^6 = number of mm^3 in one liter, 3.14 = Pi, 0.215 = radius of miscrosopic field in mm at 430X, 0.4 = depth of Palmer Cell in mm.

Water Quality

Samples were collected at the surface (0.3 m) and 0.5 m above the bottom at each station in Orange Lake and Lake Pearl. Surface samples were collected in each of the Welaka ponds. All samples were placed immediately on ice. At each station, the dissolved oxygen concentration and temperature was measured at the surface and bottom. In Lake Pearl and Orange Lake, additional oxygen and temperature readings were made at 1 m intervals from the surface to the bottom. At the Welaka ponds, diel samples were also taken. Prior to hydrilla control treatments, pH, soluble carbon and oxygen values were determined for Welaka ponds sprigged with hydrilla and for submersed macrophyte-free ponds. Single surface water samples were collected in May 1979 at each pond at 6 time intervals over a 24-hr period. Following the establishment of hydrilla, control samples were collected in February, July and October 1981 and March 1982 to determine pH, soluble carbon and oxygen in the water. Water samples were taken at 5 time intervals over a 24-hr period: (1) 1100 hours, mid-morning; (2) 1500 hours mid-afternoon; (3) 1800 to 2000 hours, dusk; (4) 000 hours; midnight, and (5) 600 to 700 hours, dawn. Upon collection, samples were immediately analyzed at Welaka for pH, total alkalinity, carbon dioxide (CO_2), bicarbonate (HCO_3) and carbonate ion (CO_2). Surface and mid-water oxygen determinations were made directly with a portable YSI 51A Temperature-Oxygen Meter in each pond. PH was measured with an Orion Model 601A Meter. Total alkalinity, carbon dioxide, bicarbonate and carbonate ion concentrations were determined by titration utilizing the methodology presented by the American Public Health Association (1976).

Other than diel samples, all water quality samples were transported on ice to the Center for Aquatic Weeds in Gainesville, Florida, and analyzed within 24 hr of collection. An Orion Model 601A pH meter calibrated against buffers at 4.0, 7.0 and 10.0 was used to measure pH. $CO2$, HCO_3 , and CO_2 concentrations were determined by titration according to standard methods (A.P.H.A. 1976). Color concentrations were determined by the platinum-cobalt method and Nessler tubes (A.P.H.A. 1976). Turbidity was measured by use of a Hach Model 2100 turbidimeter. Specific conductance was measured with a Yellow Springs Instrument Model 31 conductivity meter. Atomic absorption spectroscopy was used to determine potassium, calcium and magnesium concentrations (A.P.H.A. 1976). Chlorophyll, pheophytin, and orthophosphate concentrations were measured by standard methods (A.P.H.A. 1976). Total phosphorus concentrations were determined by the procedures of Murphy and Riley (1962) after a persulfate digestion (Menzel and Corwin 1965). Total nitrogen concentrations were measured by use of a modified Kjeldahl technique (Nelson and Sommers 1975).

Periphyton

In Spring 1980, glass slide periphyton samplers were placed at stations in the chemically treated and non treated areas of Lake Pearl. Every 2 weeks, slides were removed from the samplers, placed on ice, and returned to the laboratory. From each station, one pair of slides was examined for identification and enumeration of cells; the other 6 slides were used in pairs for chlorophyll a analysis. Counted slides were examined at 400X; all organisms were identified in 15 or more microscopic fields. Measurements were taken to establish average sizes for each species for later determination of biovolumes using nearest geometrical shape formulae (W. Taylor and E. Willen, personal communications). Slides for chlorophyll a analyses were arranged in pairs in Coplin jars with 60 ml of 90% acetone, then were sonicated for 1 minute (80% power on a Fisher Sonic dismembrator, model 300). After incubation overnight in a freezer in the dark, the supernatant was centrifuged and examined spectrophotometrically. A few direct counts of periphyton on the surface of the hydrilla leaves showed the same species in approximately the same ratios as were on the periphyton samplers. However, due to the extensive and locally unpredictable damage to host plants by the experimental treatment with herbicides, direct counting of the periphyton on hydrilla was not useful for interpreting the effects of the herbicides (Hodgson and Carter 1982).

Benthos

At Lake Pearl and Orange Lake, triplicate samples were collected monthly at each benthic station using a petite Ponar dredge (232.3 cm^2). At Orange Lake, benthic samples were collected from four habitats (open water, spatterdock, maidencane and hydrilla). At the Welaka ponds, two ponar samples were collected monthly from the middle of each pond. Samples were poured into a plastic bag and preserved with 10% formaldehyde solution stained with rose bengal. At the laboratory, each sample was washed through a standard number 30 sieve. All organisms retained in the sieve were removed and preserved with a 10% formaldehyde rose bengal solution. Organisms were identified microscopically to the lowest possible taxon and counted.

Zooplankton

Triplicate zooplankton samples were collected monthly from four stations in Lake Pearl with a 16 cm diameter Wisconsin plankton net. Vertical hauls were taken from the bottom to the lake surface. Organisms were washed from the plankton net bucket into numbered vials and preserved in a

10% formalin solution containing rose bengal stain. A 5 ml subsample was pipetted into a Ward plankton wheel where zooplankton were identified and counted. Organisms were identified to the lowest possible taxon. The same techniques were used in Orange Lake and Welaka ponds. Orange Lake samples were collected at the same stations as the benthos samples. In the Welaka ponds, two vertical zooplankton tows were taken from the middle of each pond.

Fish

Blocknets

Standing crop and biomass estimates of fish populations in Orange Lake and Lake Pearl were conducted by blocknet sampling. Blocknets were 0.081 ha in area with 3 mm bar mesh constructed as described by Lambou (1959). Blocknets were set in a square configuration, secured with weights and treated with 2.0 mg/l rotenone to achieve a total fish kill. Fish were removed from the nets as they surfaced for three consecutive days. All fish collected on the first day were sorted by species into 40 mm total length (TL) size groups, weighed and counted. Weights for fish collected on the second and third days were calculated from their lengths using length-weight data from first day samples (DuRant et al. 1979). Data from the 0.081 ha blocknets were expanded to one hectare values for data analysis.

Fish populations in Orange Lake were sampled each fall from 1977 through 1981. Sample location was stratified by vegetation type during each collection period. A minimum of three samples within habitat and year were collected in spatterdock, maidencane, hydrilla and natural open water. The habitat termed natural open water is equivalent to the profundal zone of Orange Lake. The hydrilla area sampled during this study was the portion of the lake that had previously been open water before hydrilla encroachment. Maidencane was not sampled in 1977 due to low water levels. Lake Pearl was sampled each fall from 1978 to 1982. A minimum of four samples were collected each year with two samples conducted within the chemically treated region and two in the non treated zone.

Electrofishing

A pulsed D.C. current electrofishing boat was used triannually to collect bluegill, redear (Lepomis microlophus), warmouth (Lepomis gulosus) and largemouth bass for food habit analysis, weight-length relationships and young-of-year sportfish growth in Lake Pearl and Orange Lake. Chain pickerel (Esox americanus) were collected from Orange Lake. Collections were made by size groups: largemouth bass - <75 mm, 75-150 mm, 151-250 mm, 251-350 mm and >350 mm; bluegill, redear and warmouth - <50 mm, 50-100 mm, 101-150 mm, and >150 mm. When possible, 50 fish were collected per size group per species. Fish were placed on ice immediately after capture to prevent regurgitation of stomatch contents and to provide fresh lengths and weights. Fish were brought to the Center for Aquatic Weeds for analysis. Individual total length (mm) and weight (0.1 gm) were recorded prior to removal of the digestive tracts. Food items were identified and enumerated on site or preserved individually in a 10% formaldehyde solution for later examination with a microscope.

Largemouth bass (>150 mm) captured in Lake Pearl were not sacrificed for food habits. A short, straight plastic tube was inserted into the stomach, allowing removal of stomach contents without killing the fish (Forney 1974). Individual lengths and weights were recorded prior to removal of stomach contents. Each bass was tagged with an individually numbered Floy t-bar tag prior to release and a pelvic fin was removed as a check for tag retention. The individually numbered tags allowed us to determine both individual fish growth and population estimates by the Schnabel multiple mark recapture method.

All Welaka ponds were electrofished in November 1982. Electrofishing was done around the perimeter of each pond and along two diagonals through each pond. All fish that were visible were collected and placed in aerated live wells. Fish were identified to species, weighed, and measured. Fish were then released back into their respective ponds. All largemouth bass were tagged with individually numbered floy t-bar tags.

Telemetry

Ten grass carp and nine largemouth bass were implanted with AVM radio transmitters and stocked in Lake Pearl between February 2 and April 8, 1980.

Bass were captured from Lake Pearl, implanted, and released immediately at the site of capture. Grass carp were implanted at the Austin Cary Forest Fisheries Laboratory at the University of Florida, Gainesville, Florida. These fish were held from 7 to 10 days following surgery to determine post-operative mortality.

Surgical procedure for implants was modified from Nall and Schardt (1980). Fish were anesthetized with 10 ppm quinaldine and placed in a wooden trough in an igloo cooler containing aerated water and 5 mg/l quinaldine. The water was treated with Oxytetracycline (injected-1cc/1.8 mg) and combiotic (10 mg/l). Two rows of scales were removed immediately anterior to the pelvic girdle and a 5 cm lateral incision was made in the scale removal area. The incision was made between the ribs and did not extend to the midventral line. Longitudinal incisions and incisions that extended to the midventral line were found by Nall and Schardt (1980) to reopen. Transmitters were sterilized with isopropyl alcohol and placed in the abdominal cavity between the viscera and the peritoneal lining with the antenna in a posterior position. Earlier trial implants showed that acute liver damage was a common cause of mortality. Two layers of stitches using 000 type C cromic gut suture material and 6D half circle suture needles were used in closure. One layer was completely through the body wall to reposition the peritoneal lining and increase strength. The second row consisted of shallow stitches placed between the deeper ones.

An AVM Model LA12 Portable Radio telemetry receiver was used to locate tagged fish in this study. This receiver had 12 standard 25-KHz wide channels. The frequency control was calibrated in 2.5 KHz increments, with digits every 5 KHz which permitted the operation of 24 or more transmitters without losing individual fish identification.

After a fish was located, its location was recorded on a scaled map of Lake Pearl. Water depth, temperature, dissolved oxygen and vegetation type were recorded for each location. Fish activity was calculated as number of meters traveled per day. A Lake Pearl map was divided into 0.81 ha grids. The line marking the east boundary of grids 11, 12 and 13 coincided with the delineation of the herbicide treatment portion of the lake. Because grass carp transmitters No. 15451 and 15454 and largemouth bass transmitters No. 15965, 15475 and 15449 had a short functional life and provided unreliable readings, data from these transmitters were eliminated from all analyses.

An M-Yagi hand-held fish antenna was plugged into the receiver. This general purpose antenna is composed of four elements. The antenna is directional and allowed for pinpoint location of individual fish.

RESULTS AND DISCUSSION

Vegetation

Lake Pearl

The Lake Pearl study was designed to assess the feasibility of an integrated approach to aquatic weed control utilizing aquatic herbicides and grass carp. Aquatic herbicides can effectively be used to obtain vegetation control in selected areas, however, it requires annual multiple treatments. Grass carp totally eliminate all submersed macrophytes from a water body if stocked in sufficient numbers to achieve control. By integrating chemical and biological control methods, we were attempting to develop a cost effective method of vegetation management without total elimination of all submersed macrophytes.

Previous fisheries work (Colle and Shireman 1980 and Savino and Stein 1982) has demonstrated that hydrilla coverage less than 30% may be beneficial to native fish populations, but levels higher than this have a detrimental effect upon the fish community. The submersed plants in the western half of the lake received herbicide applications from March 1980 to February 1982 (Table 3). Coupled with the herbicide treatments, a low stocking density of grass carp was initiated in July 1980. We were attempting to attain selected control of hydrilla by treating a target area to eliminate the large initial biomass of plants, then stocking grass carp for control of hydrilla regrowth in hopes of eliminating the multiple herbicide treatments that are normally required for vegetation control. Grass carp were stocked in July 1980 at a density of 12 fish/ha within the chemically treated portion of the lake. This stocking density was based on prior work by personnel from the Center for Aquatic Weeds that would maintain control of hydrilla regrowth once the initial plant biomass was removed with either aquatic herbicides or high grass carp stocking densities.

Prior to initiation of aquatic plant management strategies, total biomass of submersed vegetation within Lake Pearl was estimated with the U.S. Army Corps of Engineer's biomass sampler in March 1980. Biomass sampling revealed that hydrilla was the dominant submersed macrophyte by weight (Table 4) comprising >99% of the total vegetation biomass, therefore, submersed vegetation tracing patterns were treated as a monoculture of hydrilla. Hydrilla biomass

Table 3. Vegetation treatment in Lake Pearl.

Treatment	Date	Rate	Area (ha)
Diquat-Copper	3/26/80	Variable Test Rate	2.8
Diquat-Copper	6/11/80	4.5 kg A.I. Diq/ha 3.6 kg A.I. Cu/ha	1.0
Aquathol K	6/11/80	35.5 kg A.I./ha	2.0
Hydout	6/11/80	50.6 kg A.I./ha	1.2
Grass carp	7/1780	6.0/ha	24
Diquat-Copper	8/6/80	4.3 kg A.I. Diq/ha 3.6 kg A.I. Cu/ha	1.81
Aquathol K + Copper	8/6/80	35.5 kg A.I./ha 1.8 kg A.I. cu/ha	1.81
Diquat-Copper	9/17/80	4.5 kg A.I./ha 3.6 kg A.I. Cu/ha	1.81
Diquat-Copper	10/23/80	4.5 kg A.I. Diq/ha 3.6 kg A.I. Cu/ha	4.1
Hydout	10/23/80	25.3 kg A.I./ha	0.4
Aquathol K + Copper	10/23/80	35.5 kg A.I./ha 3.6 kg A.I. Cu/ja	4.9
Hydout	12/1/80	50.6 kg A.I./ha	1.6
Diquat + Copper	4/17/81	4.5 kg A.I. Diq/ha 3.6 kg A.I. cu/ha	2.8
Diquat	7/6/81	4.5 kg A.I./ha	4.9
Grass Carp	7/23/81	11.8/ha	24
Diquat-Copper	8/12/81	9 kg A.I. Diq/ha 7.2 kg A.I. Cu/ha	2.4
Diquat-Copper	9/24/81	4.5 kg A.I. Diq/ha 3.6 kg A.I. Cu/ha	4.1
Grass carp	12/8/81	12.5/ha	24
Aquathol K	2/4/82	35.5 kg A.I./ha	1.6
Aquathol K	2/11/82	35.5 kg A.I./ha	1.6
Diquat-Copper	2/11/82	4.5 kg A.I. Diq/ha 3.6 kg A.I. Cu/ha	.81
Grass carp	3/24/82	12.5/ha	24

Table 4. Submersed vegetation biomass and standing crop values from Lake Pearl, March, 1980. All weights are wet weights.

	Biomass (kg/m^2)		Standing Crop[a] (kg)	
	Hydrilla	Bladderwort	Hydrilla	Bladderwort
$\bar{X}$	3.32	0.018	733,720	3,978
S.E.	0.25	0.008	55,250	1,768

[a] Based on 22.1 ha of submersed vegetation cover.

averaged 3.32 kg wet weight/m^2 and total standing crop was estimated to be 7.34 $\pm$ 1.08 (95% confidence interval) x 10^5 kg wet weight. Hydrilla was collected in all biomass samples while bladderwort was found in only 14% of the samples. Although control measures were initiated in March 1980, a significant impact upon hydrilla height within the control region did not occur until August 1981 (Table 5). The initial stocking of grass carp did not have any measurable effect upon hydrilla. Herbicide applications were required at approximately two-month intervals which is the treatment schedule necessary with the various herbicides that were being applied.

Grass carp were restocked in July 1981 at a density of 12 fish/ha. The additional stocking was conducted because hydrilla regrowth was evident within the chemically treated area and no visible grass carp feeding holes were evident elsewhere in the lake. Percent cover and volume infestation (Table 6) were also approaching pretreatment levels. The treatment area required continuous herbicide applications for the remainder of 1981. Grass carp feeding areas did become apparent during late summer in non treated region, but control was less than 2 ha. By December 1982, percent cover and volume infestation levels had been reduced when compared to previous years, but the reduction could be attributed to the summer herbicide treatment. Regrowth was occurring within the herbicide zone, and grass carp control areas in the untreated regions were not increasing. Additional grass carp were stocked in December 1981 and by January 1982 hydrilla had undergone enough regrowth to increase volume infestation from 35% in December to 50% by January. Hydrilla height values for January had increased 0.4 m in the 1.5-1.9 depth strata within the chemically treated area. Herbicides were reapplied in February and a final grass carp stocking was conducted in March. Hydrilla and all other species of submersed aquatic macrophytes was totally eliminated from the system by August 1982.

Table 5. Mean hydrilla height values at varying depth strata in herbicide (HERB) and non-herbicide (NON-HERB) areas in Lake Pearl from August 1980 to December 1982.

Date	Depth Strata Meters					
	1.0-1.4		1.5-1.9		2.0-2.4	
	HERB	NON-HERB	HERB	NON-HERB	HERB	NON-HERB
August 1980	0.5*	1.0	0.7*	1.5	1.5*	2.0
October	0.8	0.9	1.9	1.5	1.7	1.9
December	0.9	0.5	1.4	1.4	1.4	1.5
February 1981	0.7	0.3	1.1	0.8	1.0	0.9
March	0.5	0.3	1.2*	0.8	1.3*	1.0
April	0.6	0.5	1.2*	0.8	1.4*	1.2
May	0.7	0.7	1.1	1.1	NC	
August	0.5*	1.1	0.6*	1.5	NC	
September	0.6*	1.5	1.0*	1.4	NC	
November	0.5*	1.0	0.5*	1.6	NC	
December	0.4*	1.0	0.6*	1.2	NC	
January 1982	0.4*	1.1	1.0*	1.3	NC	
February	0.4*	0.8	0.7*	1.0	NC	
April	0.2	0.5	0.2*	0.9	NC	
May	0.2	0.6	0.2*	0.8	NC	
July	0.2	0.4	0*	0.7	0*	0.8
August	0	0	0	0	0	0
October	0	0	0	0	0	0
December	0	0	0	0	0	0

*Significant ($P<0.05$) differences in mean values by depth strata between HERB and NON-HERB.

Table 6. Percent (%) cover and percent (%) volume infestation of hydrilla in Lake Pearl, 1979-1982 utilizing a recording fathometer.

	1979		1980		1981		1982	
Month	% Cover	% Volume	% Cover	% Volume	% Cover	% Volume	% Cover	% Volume
Jan			89*	76*			84.3	50.0
Feb			85*	61*	93.0	47.0	74.3	37.5
March	90*	32.5*	96.0	68.7	83.9	49.2	46.6	16.2
April	85.8	38.8			90.1	59.1	38.9	16.1
May	87*	50*	94.0	47.2	91.5	63.1	40.2	18.2
June	92*	69*	92.2	67.6				
July	89*	74*			93.8	71.8	35.4	12.5
Aug	86*	78*	91.9	68.8	93.2	53.8	0	0
Sept	90*	78*			90.7	68.1		
Oct	89*	80*	96.6	79.2			0	0
Nov	89*	80*			88.6	37.7		
Dec	89*	79*	95.9	63.8	83.6	35.2	0	0

*Data from point-line transects

Although submersed vegetation was eliminated, emergent vegetation has increased in Lake Pearl. Spatterdock and fragrant water lily stands have increased in both density and area (Table 7). Increases can be attributed to the water level decrease in 1981 (Table 8), which allowed encroachment of these plants into areas that had previously been too deep. The nut rush band around the lake perimeter, however, was almost eliminated during low water. After the increase in water level during 1982, there was a more mixed shoreline community. Stands of cattail, arrowhead, pickerelweed, maidencane and water pennywort are now present along the shoreline. By January 1983, grass carp had not begun to impact the emergent or floating leafed vegetation. Shoreline urban development, however, is approaching 60% of the lake's perimeter. Homeowners have been removing all vegetation at the lake's edge; therefore, as development continues so will shoreline vegetation removal.

Integration of aquatic herbicides and grass carp resulted in the control of hydrilla in Lake Pearl, but we were unable to attain a specific (15 or 20%) level of control. Until grass carp were stocked in sufficient numbers for total plant eradication, they did not have any measurable impact upon the submersed plant community. The lower stocking rates also did not cause a reduction in the amount of herbicides used in the system. Our study demonstrates that if total eradication of hydrilla is not a management goal, grass carp should not be used for vegetation control unless intensive management is utilized.

Table 7. Percent coverage of aquatic plants in Lake Pearl in 1979 and 1982.

Plant	1979 % Coverage	1982 % Coverage
Alternanthera philoxeroides (Mart.) Griesb.	Trace	Trace
Eichhornia crassipes (Mart.) Solms	2	Trace
Eleocharis acicularis (L.) R. & S.	Trace	0
Hydrilla verticillata Royle	5	0
Hydrilla surface matted	14	0
Hydrocotyle umbellata (L.)	Trace	Trace
Myriophyllum heterophyllum Michx	Trace	0
Najas quadalupensis (Sprengel) Nagnus	Trace	0
Nuphar advena Aiton	2	7
Nymphaea odorata Aiton	2	3
Panicum repens L.	1	1
Pontederia cordata L.	1	1
Sagittaria lancifolia L.	1	1
Salvinia rotundifolia Wild.	Trace	Trace
Scleria sp.	4	Trace
Typha latifolia L.	1	1
Utricularia subulata L.	14	0
Utricularia inflata Walt.	10	10
Bareground	11	90

Table 8. Hydrilla coverage (ha) and hydrilla volume (m x 10) values in Lake Pearl, 1979-1982, utilizing a recording fathometer.

Month	1979		1980		1981		1982	
	Hydrilla Coverage (ha)	Hydrilla Volume (m^3x 10^4)	Hydrilla Coverage (ha)	Hydrilla Volume (m^3x 10^4)	Hydrilla Coverage (ha)	Hydrilla Volume (m^3x 10^4)	Hydrilla Coverage (ha)	Hydrilla Volume (m^3x 10^4)
Jan							16.8	16.9
Feb					19.8	18.3	14.5	11.7
March			20.4	32.5	17.7	18.5	10.1	4.9
April	18.4	21.7	20.2	22.3	17.8	20.1	8.1	5.3
May					17.8	19.7	8.3	6.0
June			20.1	31.9				
July					18.0	19.6	7.4	4.5
Aug			19.9	28.9	17.6	13.5	0	0
Sept					17.3	18.6		
Oct			20.3	32.0			0	0
Nov					16.7	10.3		
Dec			19.9	25.0	15.7	9.6	0	0

Orange Lake

Hydrilla was first reported in Orange Lake in 1974 when estimated coverage was 20 ha (Krummrich et al. 1979). Coverage increased to 109 ha in 1975 and by 1976 and 1977 total lake coverage was over 80% (Table 9). Prior to the introduction of hydrilla, at least 50% of the lake was devoid of aquatic vegetation. Aquatic macrophytes had been confined to an extensive littoral region dominated by spatterdock. All submersed vegetation prior to hydrilla infestation was confined within the spatterdock community and consisted primarily of coontail, bladderwort and southern naiad. The spatterdock community was completely vegetated with hydrilla during 1976 and 1977 (Table 10).

Following the near drought conditions that occurred in 1977, the water level of Orange Lake increased 1.73 m during Spring 1978. Hydrilla coverage decreased to 66 ha in 1978. This substantial decrease in hydrilla was not directly related to the actual increase in water depth during 1978, but to a concurrent phytoplankton bloom that probably resulted because of a large influx of nutrients from the watershed and a release of nutrients from previously exposed lake bottom. The bloom physically reduced bottom light levels to a value below which hydrilla could not survive. The bloom did not persist after 1978, and viable tubers produced prior to this time period began germinating in 1979 when bottom light levels were sufficient to permit plant growth.

Hydrilla coverage was expanding in 1979, but the majority of the regrowth was occurring in the profundal region of the lake. Point-line transects and recording fathometer tracings (Figures 7-11) showed that hydrilla had completely reinvaded the 2 m contour by 1980 and during 1981 was present to the 2.5 m contour. The spatterdock and maidencane communities were virtually hydrilla-free during 1978 and 1979; however, by 1980, hydrilla was present within the entire littoral vegetation community.

Table 9. Percent coverage of aquatic vegetation in Orange Lake.

	YEAR								
Habitat	1974[a]	1975[a]	1976[a]	1977	1978	1979	1980	1981	1982
Nuphar luteum[b]				36.0	48.6	48.6	48.6	48.6	48.6
Panicum hemitomon[b]				0.2	0.4	0.4	0.4	0.4	0.4
Hydrilla verticillata[c]	0.4	0.9	47.0	59.0	0.2	16.5	17.1	21.9	28.1
Open water			5.0	5.0	50.8	34.5	33.9	29.1	23.0

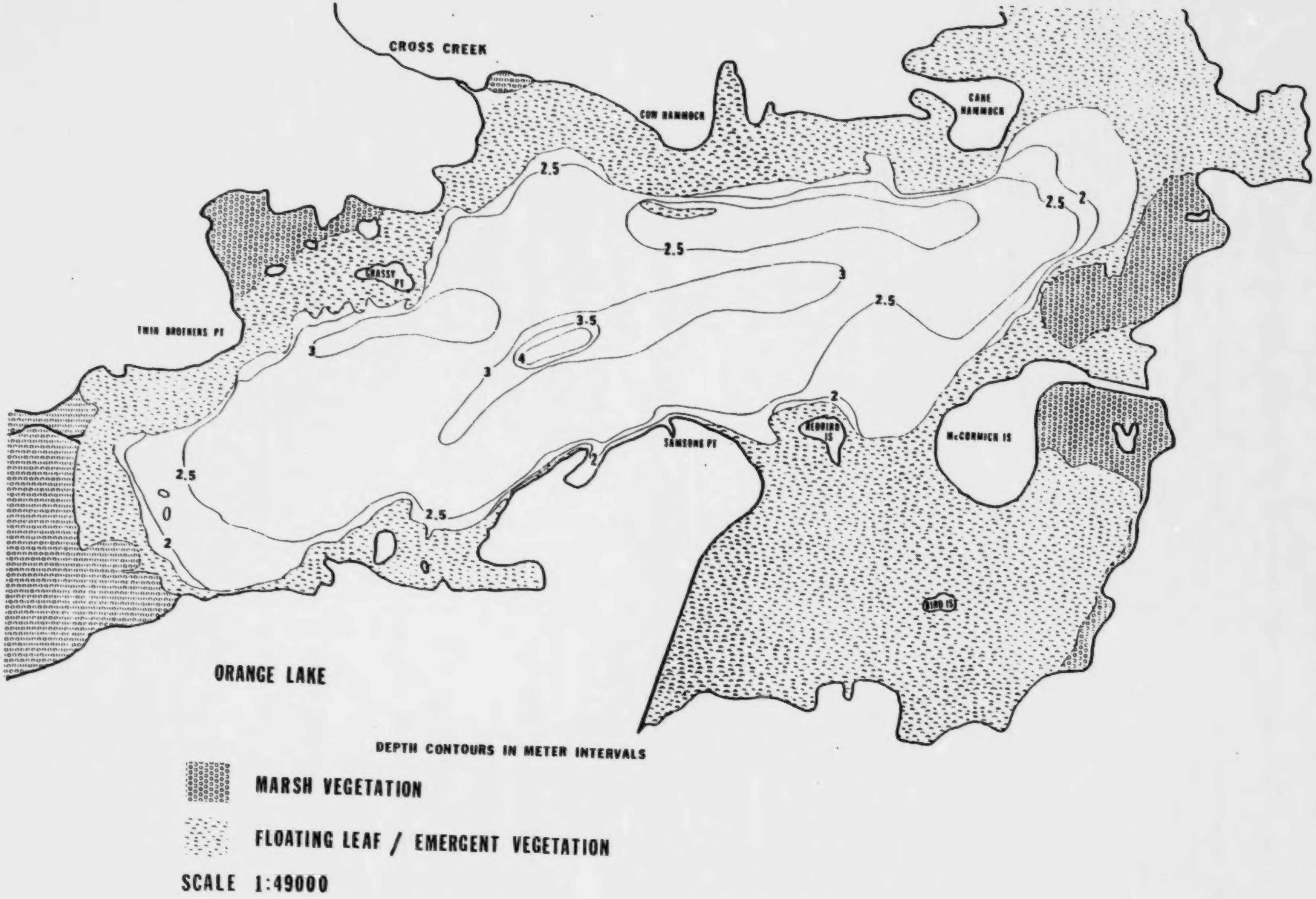
[a] Data from Krummrich (1980)

[b] *Nuphar luteum* and *Panicum hemitomon* habitats after 1979 were 100% *Hydrilla verticillata* infested.

[c] *Hydrilla verticillata* coverage only in the profundal region of Orange Lake.

Table 10. Plant species encountered along transect line in Orange Lake.

Scientific Name	Common Nmae
Alternanthera philoxeroides (Mart.) Griesb.	Alligatorweed
Cabomba caroliniana Gray	Green fanwort
Ceratophyllum demersum L.	Coontail
Cladium jamaicense Crantz.	Sawgrass
Eichhornia crassipes (Mart.) Solms.	Waterhyacinth
Hydrilla verticillata Royle	Hydrilla
Hydrocotyle umbellata (L.)	Water pennywort
Juncus effusus L.	Soft rush
Lemna minor L.	Common duckweed
Limnobium spongia (Bosc.) Steud.	Frog's-bit
Myriophyllum brasiliense Camb.	Parrot's-feather
Najas quadalupensis (Sprengel) Magnus	Southern naiad
Nelumbo lutea (Wild.) Pers.	American lotus
Nuphar advena Aiton	Yellow cow-lily
Panicum hemitomon Schult.	Maidencane
Panicum geminatum	Torpedograss
Salvinia rotundifolia Wild.	Common salvinia
Tolypella (A. Braun) Leonhardi	Algae-Phylum Chlorophyta
Typha latifolia	Cattail
Utricularia inflata Walt.	Big floating bladderwort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COW HAMMOCK
CANE HAMMOCK
GRASSY PT
TWIN BROTHERS PT
SAMSONS PT
REDBIRD IS
McCORMICK IS
BIRD IS
2.5
2
3
3.5
4
ORANGE LAKE
DEPTH CONTOURS IN METER INTERVALS
▨ MARSH VEGETATION
░ FLOATING LEAF / EMERGENT VEGETATION
SCALE 1:49000

Figure 7. Hydrilla coverage June 1978, Orange Lake, Florida.

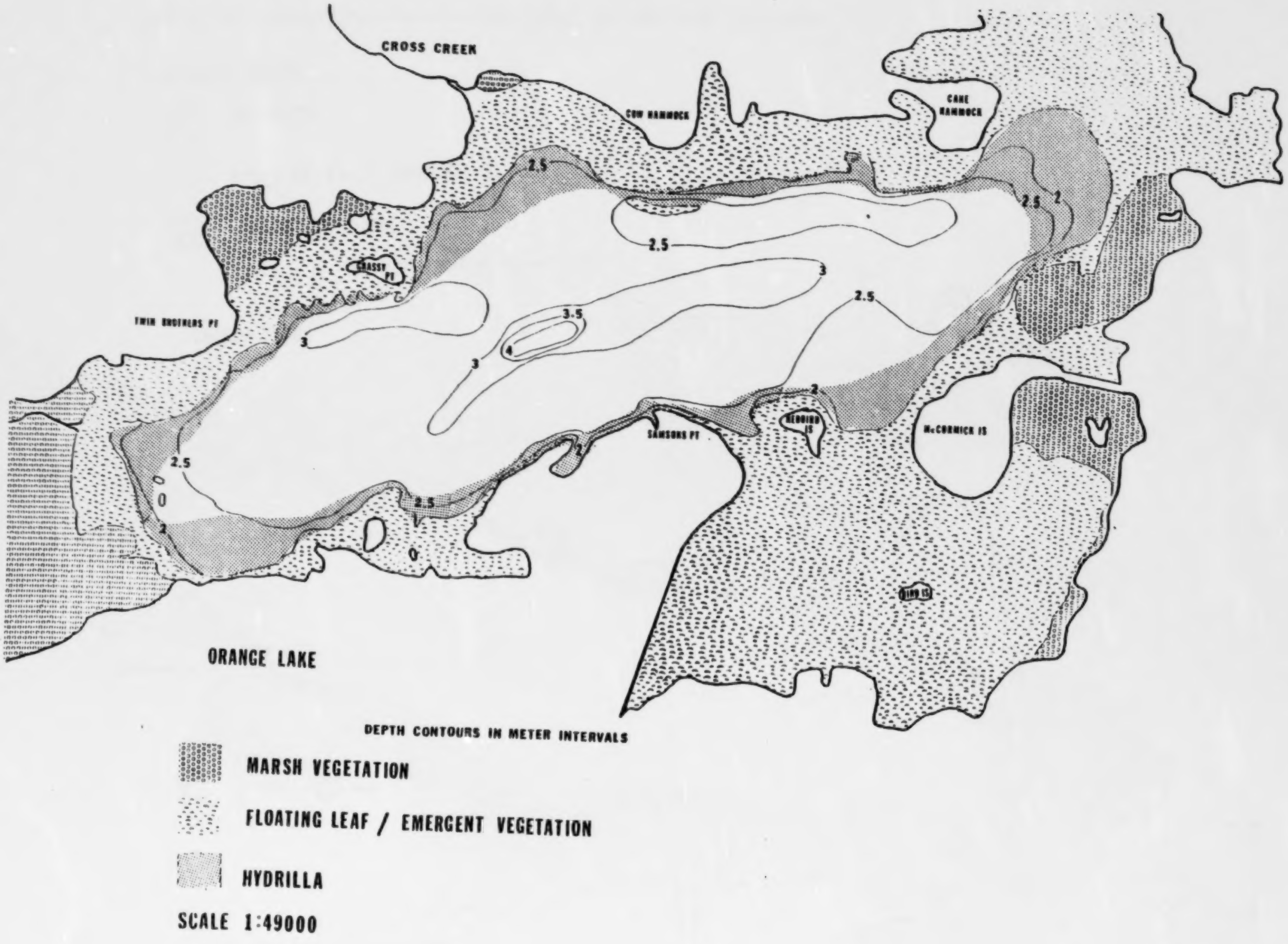
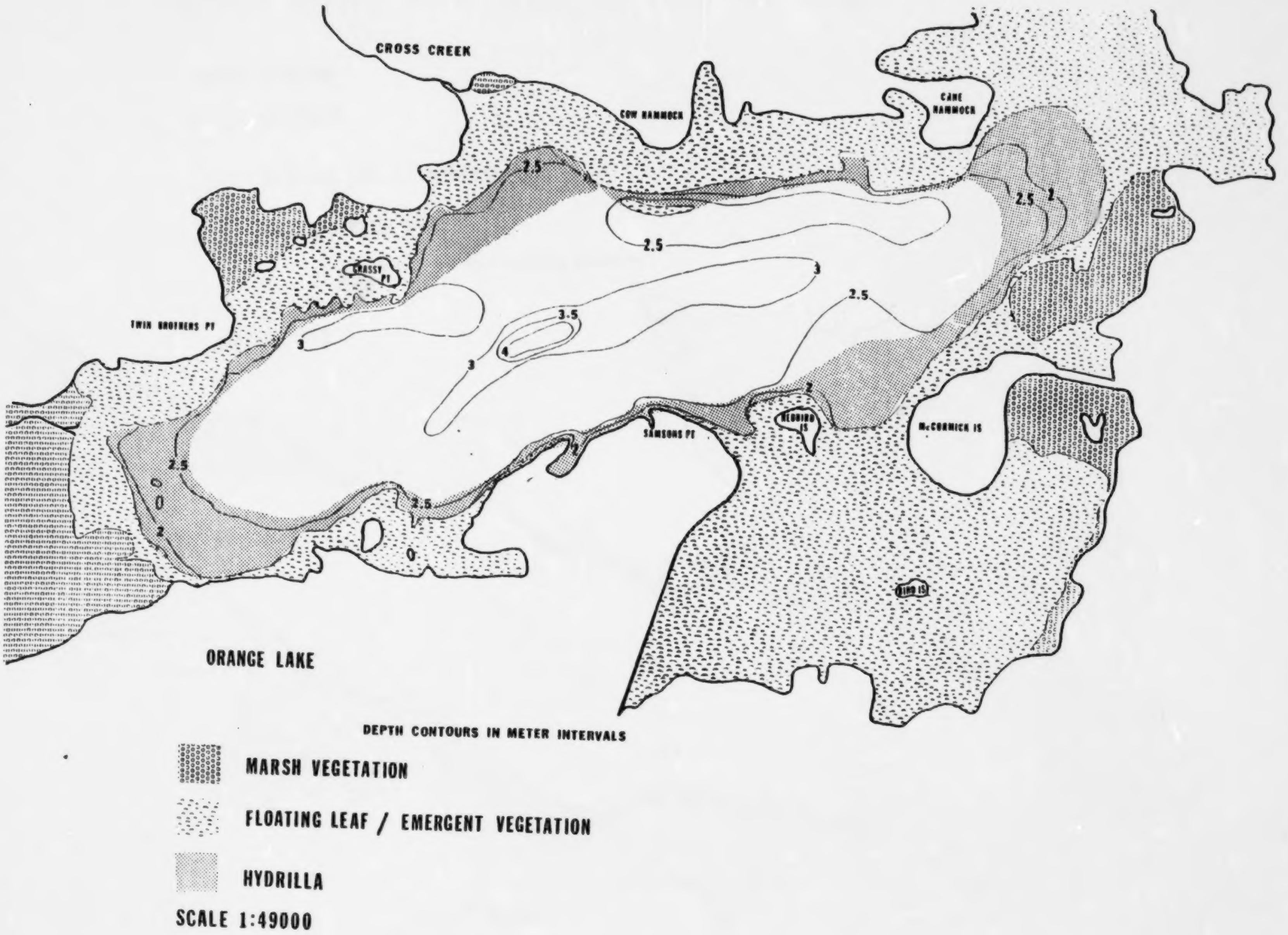

CROSS CREEK
COW HAMMOCK
CANE HAMMOCK
GRASSY PT
TWIN BROTHERS PT
SAMSONS PT
REDBIRD IS
McCORMICK IS
BIRD IS
2
2.5
3
3.5
4
ORANGE LAKE
DEPTH CONTOURS IN METER INTERVALS
MARSH VEGETATION
FLOATING LEAF / EMERGENT VEGETATION
HYDRILLA
SCALE 1:49000

Figure 8. Hydrilla coverage January 1980, Orange Lake, Florida.


CROSS CREEK
COW HAMMOCK
CANE HAMMOCK
TWIN BROTHERS PT
GRASSY PT
SAMSONS PT
REDBIRD IS
McCORMICK IS
BIRD IS
ORANGE LAKE
2.5
2
2.5
3
2.5
3.5
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3
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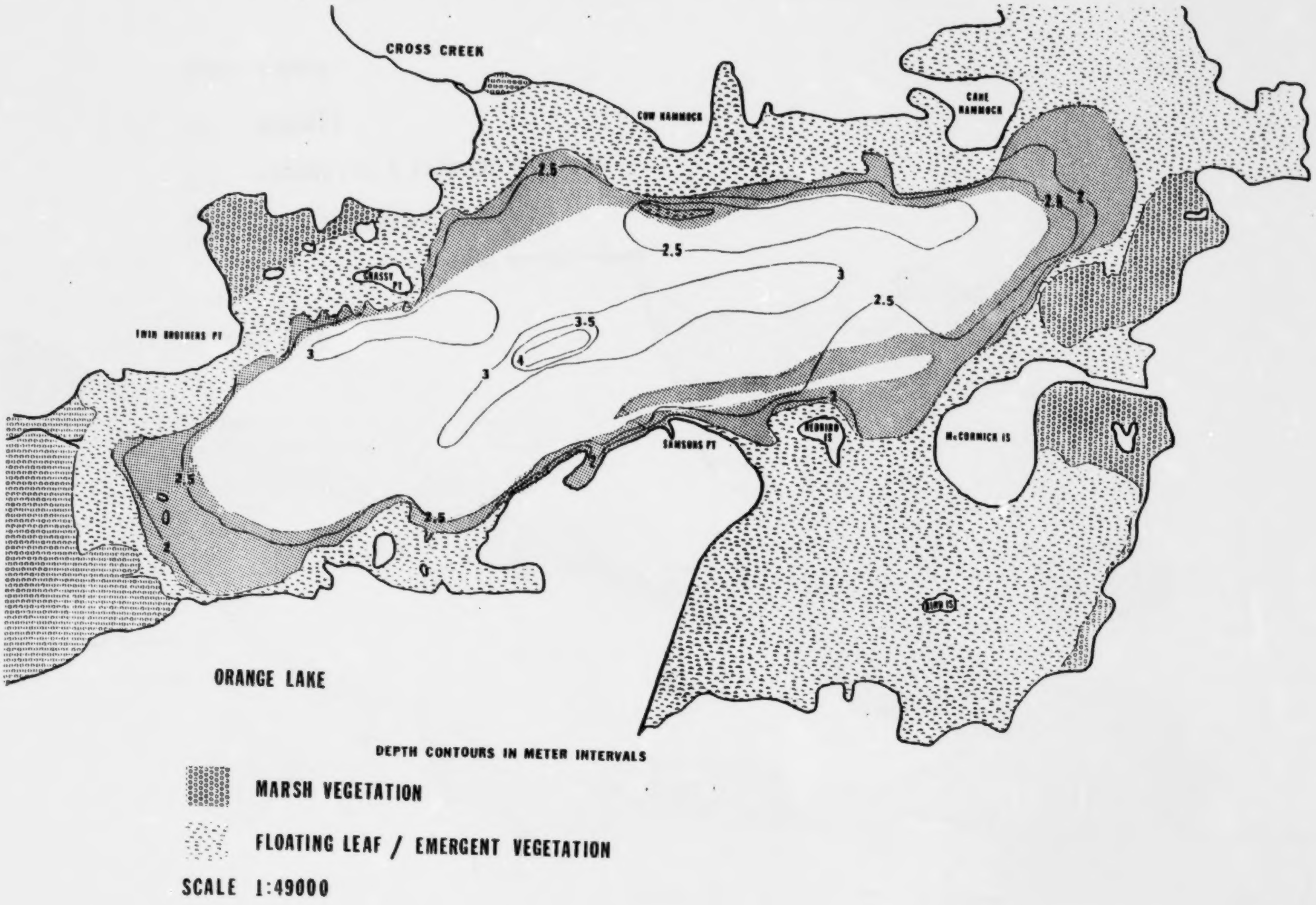
2
2
2.5
2.5
2
DEPTH CONTOURS IN METER INTERVALS
MARSH VEGETATION
FLOATING LEAF / EMERGENT VEGETATION
HYDRILLA
SCALE 1:49000

Figure 9. Hydrilla coverage June 1980, Orange Lake, Florida.


CROSS CREEK
COW HAMMOCK
CANE HAMMOCK
GRASSY PT
TWIN BROTHERS PT
REDBIRD IS
McCORMICK IS
BIRD IS
SAMSONS PT
ORANGE LAKE
2.5
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4
2
2
2
DEPTH CONTOURS IN METER INTERVALS
MARSH VEGETATION
FLOATING LEAF / EMERGENT VEGETATION
SCALE 1:49000

Figure 10. Hydrilla coverage June 1981, Orange Lake, Florida.

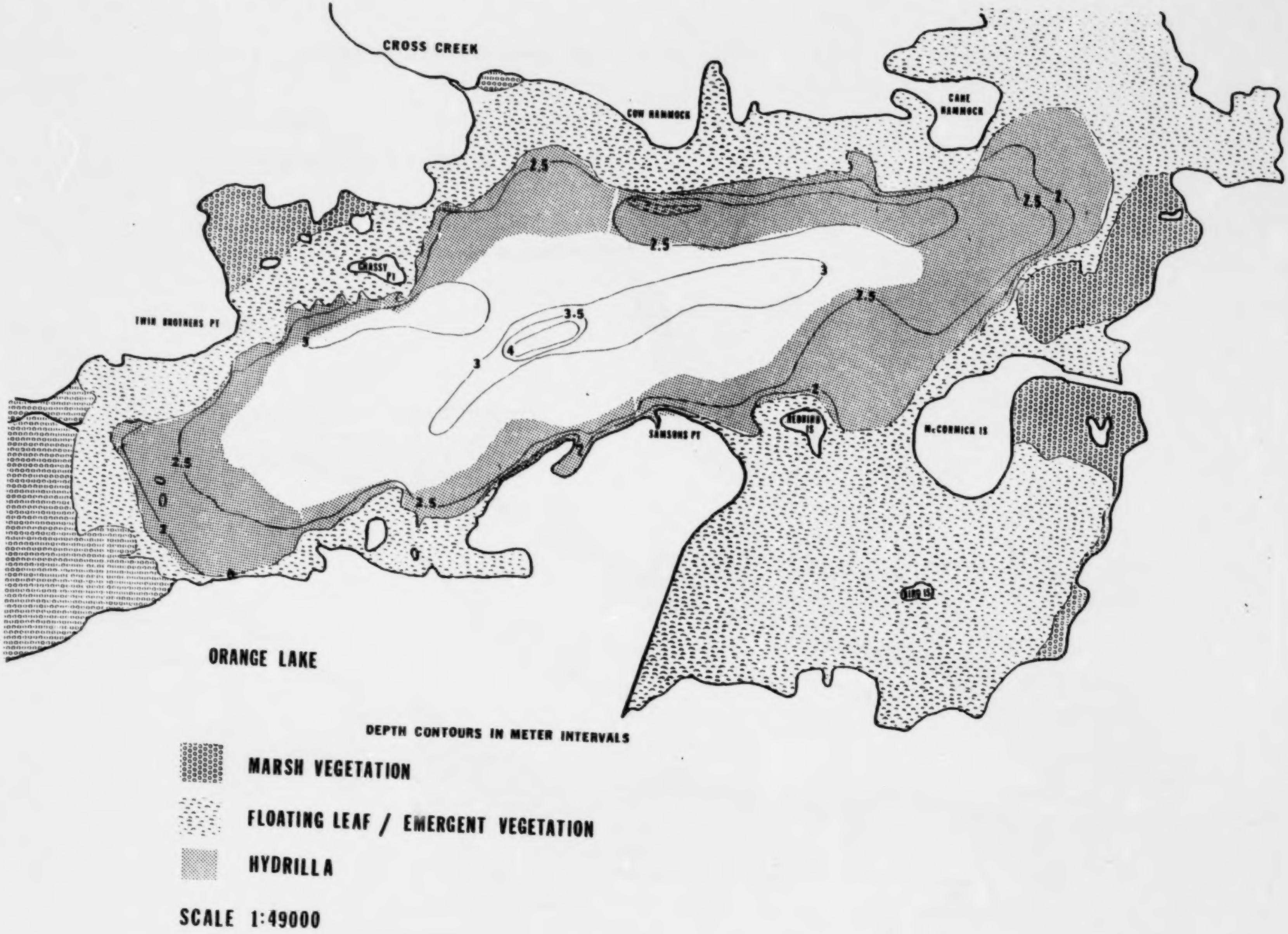
CROSS CREEK
COW HAMMOCK
CANE HAMMOCK
TWIN BROTHERS PT
GRASSY PT
SAMSONS PT
HEDDING IS
McCORMICK IS
BIRD IS
ORANGE LAKE
2.5
2.5
2.5
2.5
2.5
2.5
2.5
2
2
2
3
3
3
3.5
4
DEPTH CONTOURS IN METER INTERVALS
MARSH VEGETATION
FLOATING LEAF / EMERGENT VEGETATION
HYDRILLA
SCALE 1:49000

Figure 11. Hydrilla coverage, February 1982, Orange Lake, Florida.

In all study years, maximum plant height and coverage occurred during October and November. From January to March, a winter dieback or a dropping out of dense surface mats happened due to cooler climatic conditions. Although plant height was greatly reduced during senescence, plant coverage was not altered (Figures 12, 13 and 14).

Coontail and southern naiad the two dominant native submersed plants in Orange Lake, decreased in frequency of occurrence and percent coverage during periods of peak hydrilla growth (July to November). As hydrilla declined during the winter samples, coontail and southern naiad increased in frequency of occurrence and percent coverage. Dominant emergent and floating leafed plants (maidencane and spatterdock) in Orange Lake did not undergo any reduction in coverage or frequency of occurrence as hydrilla expanded into both of these vegetation communities. Native emergent and floating leafed plants most likely did not undergo reductions in coverage with an increase in hydrilla because the emergent and floating leafed plants could reach the water's surface through reserved nutrients within the root system. After reaching the surface, they were able to photosynthesize because they were out of the hydrilla mat. Therefore, if emergent and floating leafed plants are present prior to hydrilla infestation they will continue to grow, whereas native submersed plants will be greatly reduced as a result of hydrilla encroachment because they are not able to utilize available free CO_2 at light intensities as low as hydrilla (Van et al. 1976). The ability of hydrilla to utilize CO_2 at reduced light intensities also allows it to grow in limnetic areas where native submersed plants can not exist.

Welaka Ponds

Prior to vegetation treatment, background data was collected, and hydrilla was planted and allowed to grow before treatments were initiated. Treatment arrangements are shown in Figure 15.

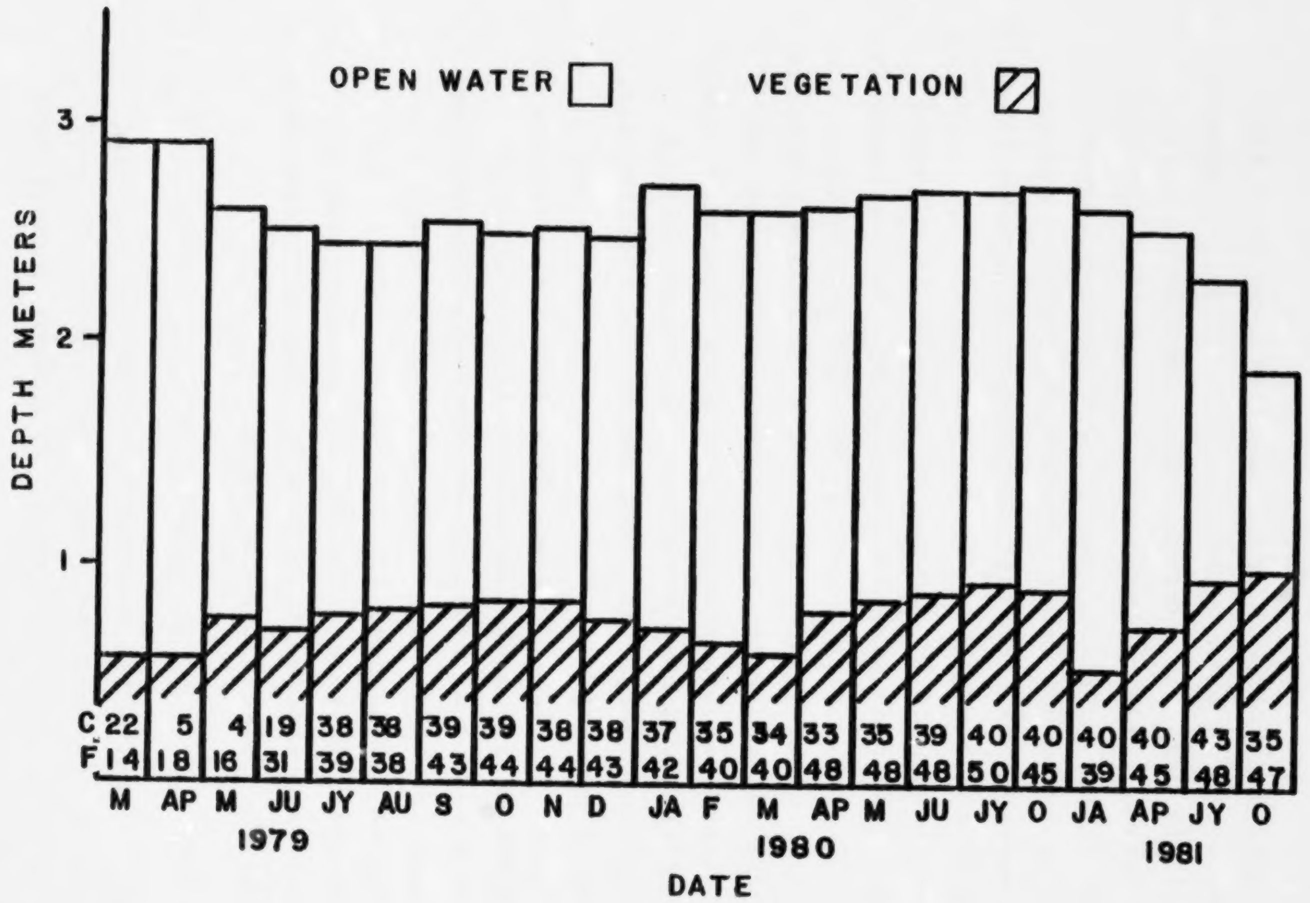

Figure 12. Vegetation transect line 1. Orange Lake, Florida (C=% coverage of hydrilla, F=% frequency of hydrilla).

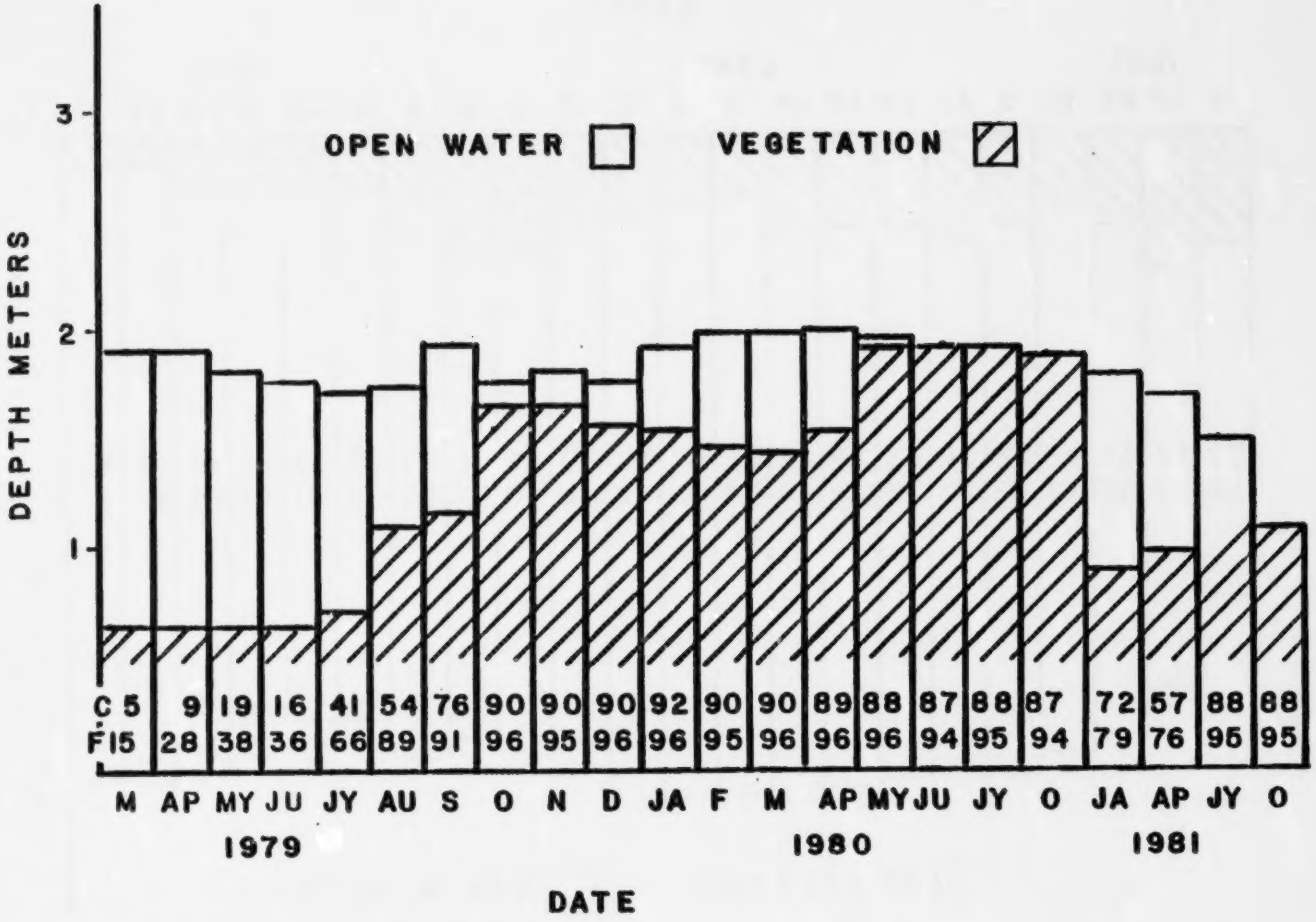

Figure 13. Vegetation transect line 2. Orange Lake, Florida (C=% coverage of hydrilla, F=% frequency of hydrilla).

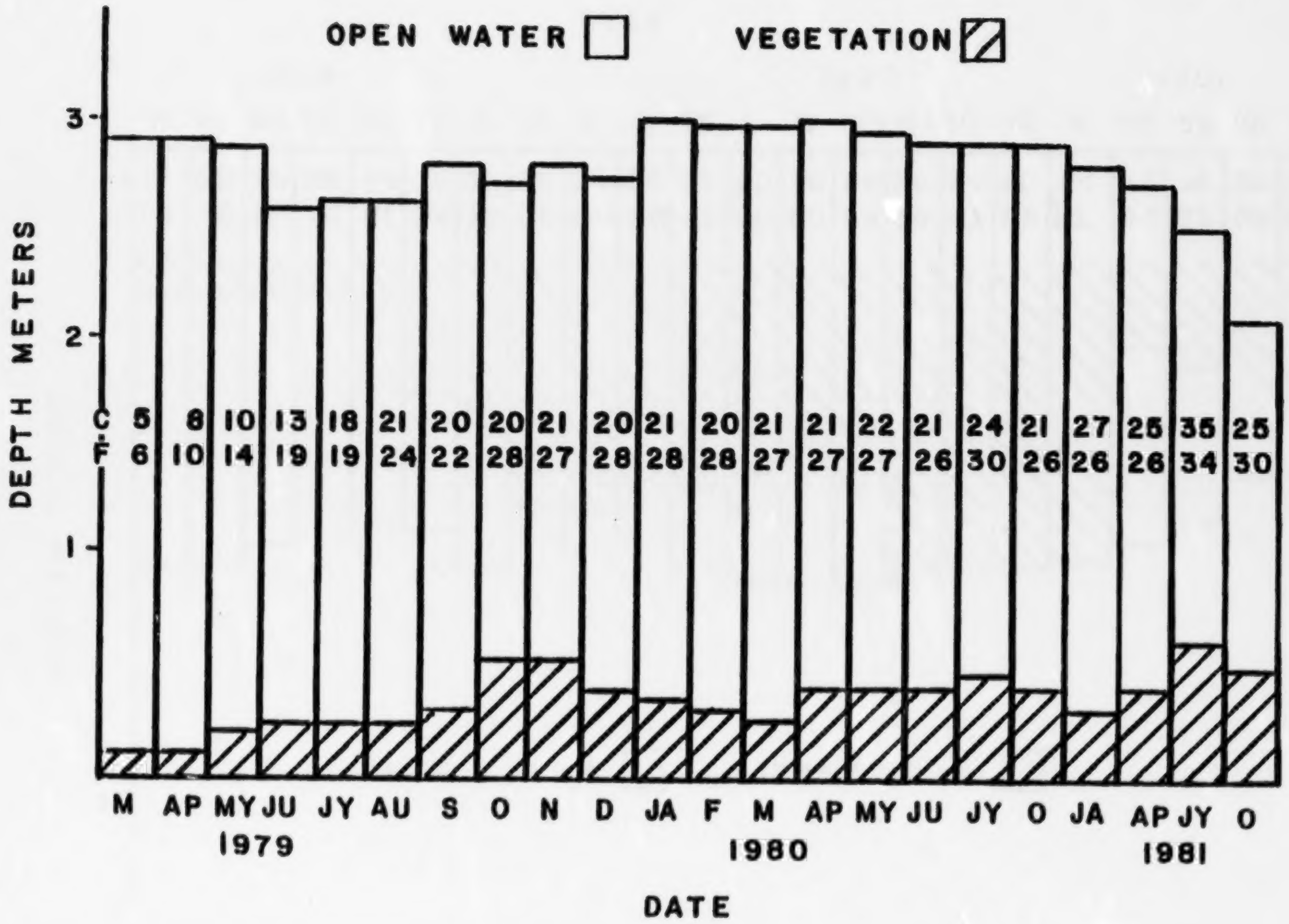

Figure 14. Vegetation transect line 3. Orange Lake, Florida (C=% coverage of hydrilla, F=% frequency of hydrilla).

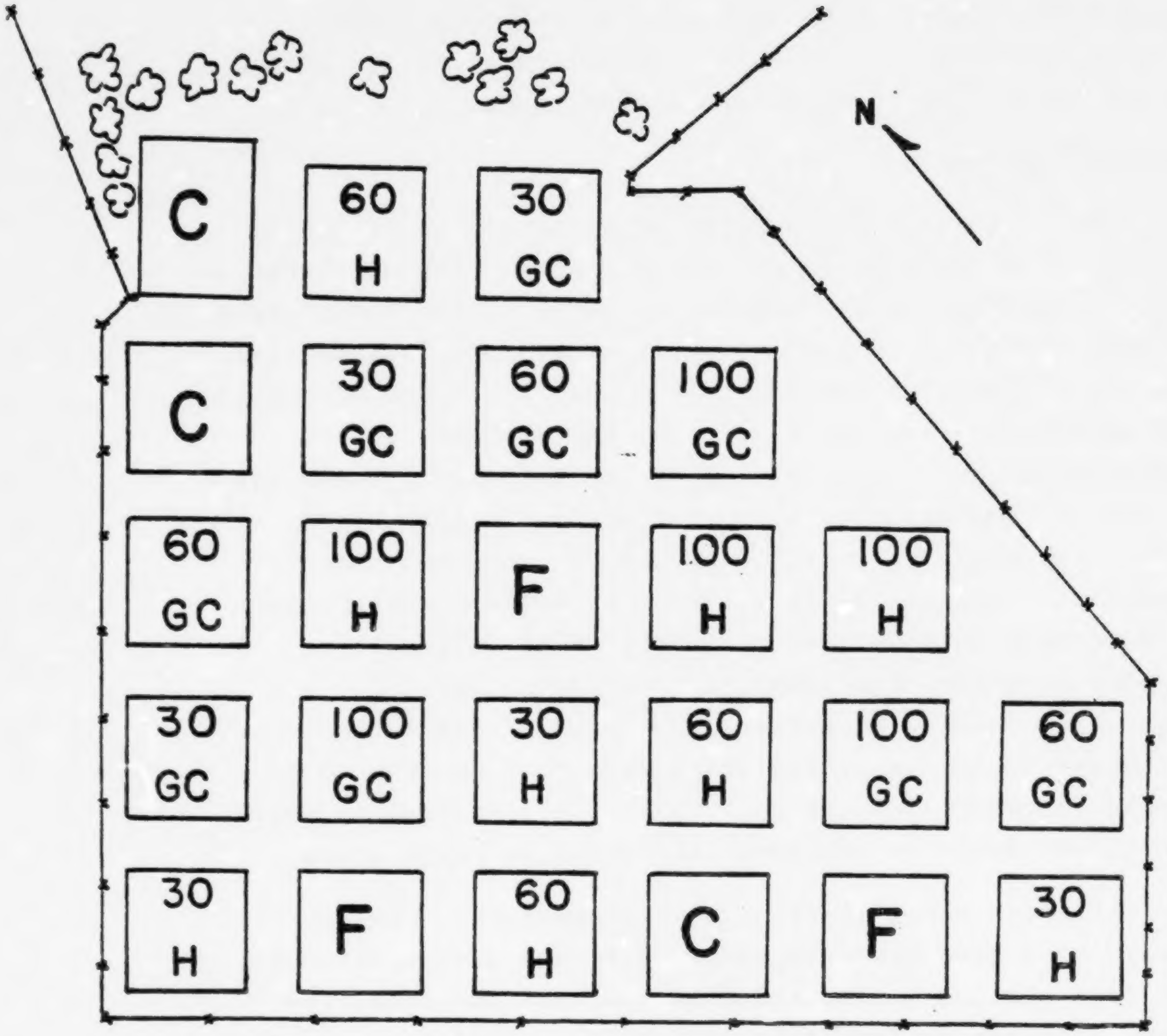
N
C
60 H
30 GC
C
30 GC
60 GC
100 GC
60 GC
100 H
F
100 H
100 H
30 GC
100 GC
30 H
60 H
100 GC
60 GC
30 H
F
60 H
C
F
30 H

Figure 15. Treatment ponds Welaka, Florida (F=fertilizer, H=herbicides, GC=grass carp and C=control).

Grass carp were introduced into nine of the Welaka ponds in November 1979 to evaluate their effectiveness for 30, 60 and 100% vegetation control. Herbicide treatments were initiated in May 1980. Three fertilization ponds (fish management ponds) were treated to evaluate phytoplankton competition for control of macrophytes. Mechanical harvesting was also employed in these ponds to remove vegetation. Three ponds were used as controls (100% vegetation cover) to evaluate seasonal chemical and biotic cycles as related to total vegetation cover.

Grass carp ponds.

All grass carp ponds required at least two stockings and one pond required seven separate grass carp stockings in order to achieve target vegetation levels. The total number of fish stocked in a pond varied from 89 in a 100% control pond to 11 in a 70% control pond (Table 11). The necessity for additional fish in these ponds was probably due to differential grass carp mortality in the ponds. Ponds 23, 22 and 17, for example, were shallow, clear water ponds where fish could be easily captured by birds and other predators. Because stocking rates to achieve control were so different in each control level, it is difficult to develop stocking rate models for different desired vegetation levels. Constant inspection of vegetation abundance is necessary and grass carp must be stocked as needed to reduce vegetation. This is easily done in small ponds, but would be extremely difficult in large lakes.

Although target levels in all treatments were not exact, they were close to expected values (Table 12). In the 100% control ponds, hydrilla declined steadily from first stocking in September 1979 to June 1981 when desired control levels were achieved (Figure 16). In each study year, yearly growth cycles occurred, but oscillations declined as vegetation was removed. From June 1981 until December 1982, 100% control was achieved. In the grass carp ponds, no other control methods were used, therefore, native

Table 11. Stocking dates and numbers of grass carp introduced into Welaka ponds for vegetation control.

% Vegetation Treatment	Pond	Stocking Dates							
		11-23-79	6-6-79	9-30-80	4-31-81	5-21-81	7-28-81	12-10-81	Total
100	13	16	0	5	2	0	0	0	23
100	7	4	0	3	6	0	8	10	31
100	23	8	2	3	8	10	12	15	58
70	12	16	5	3	12	0	0	0	36
70	14	8	0	3	0	0	0	0	11
70	22	4	4	4	0	4	6	10	32
30	8	4	3	4	16	10	*	*	37
30	14	8	2	3	16	6	16	0	51
30	17	16	4	3	30	20	12	4	89
Total		84	20	31	90	50	54	39	368

* Pond Dry

Table 12. Estimated percent volume of all vegetation in Welaka Ponds.

Pond	Treatment	Date				
		6-31-79	9-27-79	10-30-79	11-28-79	1-17-80
1	100 veg	90	100	95	90	80
2	30 H	40	80	70	80	70
3	0 F	20	50	50	75	10
4	60 H	70	95	95	90	70
5	30 H	20	80	75	80	40
6	60 H	70	70	70	95	60
7	0 GC	60	80	95	90	80
8	60 GC	80	95	100	95	90
9	0 H	60	60	70	75	60
10	0 F	30	40	50	80	10
11	0 H	100	90	95	90	80
12	30 GC	90	95	95	95	80
13	0 GC	50	90	100	95	50
14	30 GC	95	95	90	90	90
15	60 GC	90	95	90	95	95
16	100 veg	80	100	90	95	95
17	60 GC	30	100	100	100	95
18	30 H	50	95	100	95	90
19	100 veg	40	100	100	100	100
20	0 F	0	5	20	10	10
21	60 H	30	100	100	100	100
22	30 GC	50	90	95	100	100
23	0 GC	30	90	95	95	90
24	0 H	40	80	100	90	85

Table 12. Continued.

Pond	Date 2-13-80	3-31-80	4-23-80	5-28-80	7-8-80	7-29-80
1	80	85	70	90	95	95
2	70	70	90	80	80	60
3	5	50	50	20	90	50
4	60	60	80	80	60	60
5	50	50	60	70	20	20
6	60	70	70	60	20	20
7	80	80	60	60	20	30
8	80	80	70	80	50	70
9	50	50	70	80	20	10
10	5	10	20	20	60	20
11	80	90	90	80	30	10
12	90	90	80	90	90	80
13	50	60	90	90	40	40
14	90	90	80	80	60	70
15	100	95	100	100	90	90
16	100	95	100	100	100	100
17	95	95	100	90	100	90
18	95	95	100	95	95	80
19	100	100	100	100	100	100
20	5	10	10	10	5	20
21	100	95	95	90	95	90
22	100	95	95	90	90	90
23	90	90	90	90	70	70
24	80	90	95	95	80	60

Table 12 Continued.

Pond	Date 8-29-80	9-29-80	10-30-80	12-3-80	1-30-81	2-27-81	3-31-81
1	95	100	100	100	95	95	95
2	50	40	80	80	80	80	60
3	10	50	60	40	60	60	30
4	30	70	80	80	70	70	60
5	20	20	10	10	20	30	30
6	30	30	40	40	30	30	30
7	30	80	70	10	5	5	5
8	80	20	10	60	70	80	50
9	30	15	10	20	20	30	10
10	40	30	50	50	50	60	40
11	20	20	20	30	30	40	20
12	30	80	70	60	80	80	60
13	60	40	20	30	20	20	5
14	60	40	30	30	30	40	30
15	80	80	70	70	95	80	70
16	100	100	100	100	70	100	95
17	95	90	90	90	85	95	90
18	100	80	80	90	80	90	60
19	60	100	100	100	100	100	100
20	30	40	60	60	90	80	50
21	90	90	80	80	70	80	80
22	80	80	80	80	80	50	60
23	50	60	60	50	50	70	50
24	60	80	30	50	30	40	30

Table 12 Continued.

Pond	Date 7-7-81	7-29-81	9-1-81	9-30-81	11-3-81	1-7-82
1	95	95	95	95	95	90
2	40	50	30	30	40	40
3	45	30	40	50	50	50
4	60	70	50	60	60	60
5	30	30	30	40	50	50
6	40	40	50	50	50	20
7	5	10	10	10	10	10
8	50	50	50	50	50	50
9	10	10	5	5	5	5
10	40	20	30	40	40	50
11	20	30	5	5	10	5
12	40	40	40	50	50	50
13	5	5	5	5	5	5
14	30	30	30	30	40	40
15	70	70	70	70	80	80
16	95	100	100	100	95	95
17	-	-	-	-	-	-
18	-	-	-	-	-	-
19	-	-	-	-	-	-
20	50	20	40	50	60	60
21	70	80	60	60	70	70
22	50	50	50	50	60	50
23	30	40	30	30	20	5
24	5	10	0	0	0	5

Table 12 Continued.

Pond	Date 5-3-82	7-16-82	9-1-82	11-3-82	12-24-82
1	90	90	95	95	95
2	40	40	50	40	60
3	80	10	70	30	10
4	70	80	80	70	70
5	60	60	70	60	40
6	20	20	30	30	30
7	10	10	20	20	20
8	40	30	40	20	20
9	5	10	20	30	10
10	60	10	60	20	20
11	10	20	10	10	10
12	40	40	50	50	50
13	5	10	10	10	5
14	30	30	30	20	20
15	60	50	50	50	50
16	90	90	95	95	95
17	-	-	-	-	-
18	-	-	-	-	-
19	-	-	-	-	-
20	90	20	90	20	30
21	80	90	60	80	80
22	40	40	30	30	30
23	0	0	0	0	0
24	10	20	10	10	0

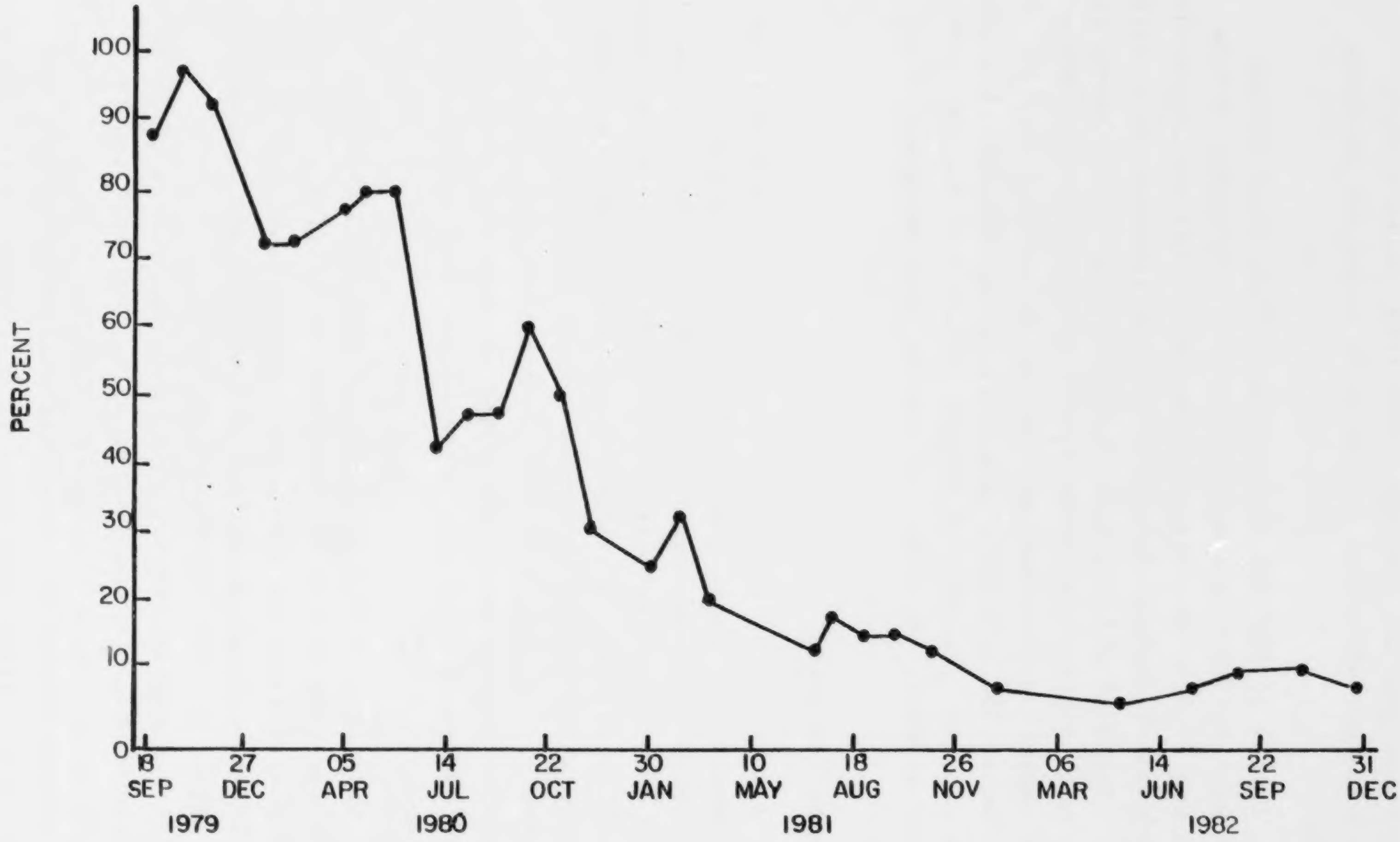

Figure 16. Percent vegetation remaining in 100% control grass carp ponds Welaka, Florida.

vegetation such as fragrant water lily, pickerelweed, cattails and maidencane persisted or increased in these ponds.

In the 30 and 60% vegetation control ponds it was difficult to reach and maintain target vegetation levels (Figures 17 and 18). In both the 30 and 60% control groups, submersed vegetation levels were below expected rates (Table 12). Emergent and floating leafed vegetation increased in all ponds which resulted in higher mean vegetation levels than indicated by submersed vegetation levels. In both treatments (30 and 60%), plant levels in December 1982 were very similar. Management levels achieved in the 60% control ponds, however, occurred at a faster rate (Figures 17 and 18).

Herbicide Ponds

A total of 13 herbicide applications were made after treatments were begun (Table 13). Frequent use of herbicides have been required for two reasons: (1) the rapid growth rate and extended growing season of the plants and (2) management of plants to maintain specified amounts of vegetation within the ponds without removing all vegetation. It was difficult to maintain exact target levels of vegetation within ponds of this size because a small amount of herbicide often caused considerable plant removal.

Endothall (7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid) was used solely for treatment of hydrilla. Diquat (6,7-dihydrodipyrido[1,2-α:2'1'-c]pyrazinediium ion) was applied to control spikerush, southern naiad, bladderwort and hydrilla. The butoxyethyl ester of 2,4-dichlorophenoxyacetic acid, a granular form of 2-4D, was used to control fragrant water lily, pennywort and to a lesser extent pickerelweed. Glyphosate (N-(phosphonomethyl)glycine) was sprayed on cattail and pickerelweed along pond banks to facilitate their control.

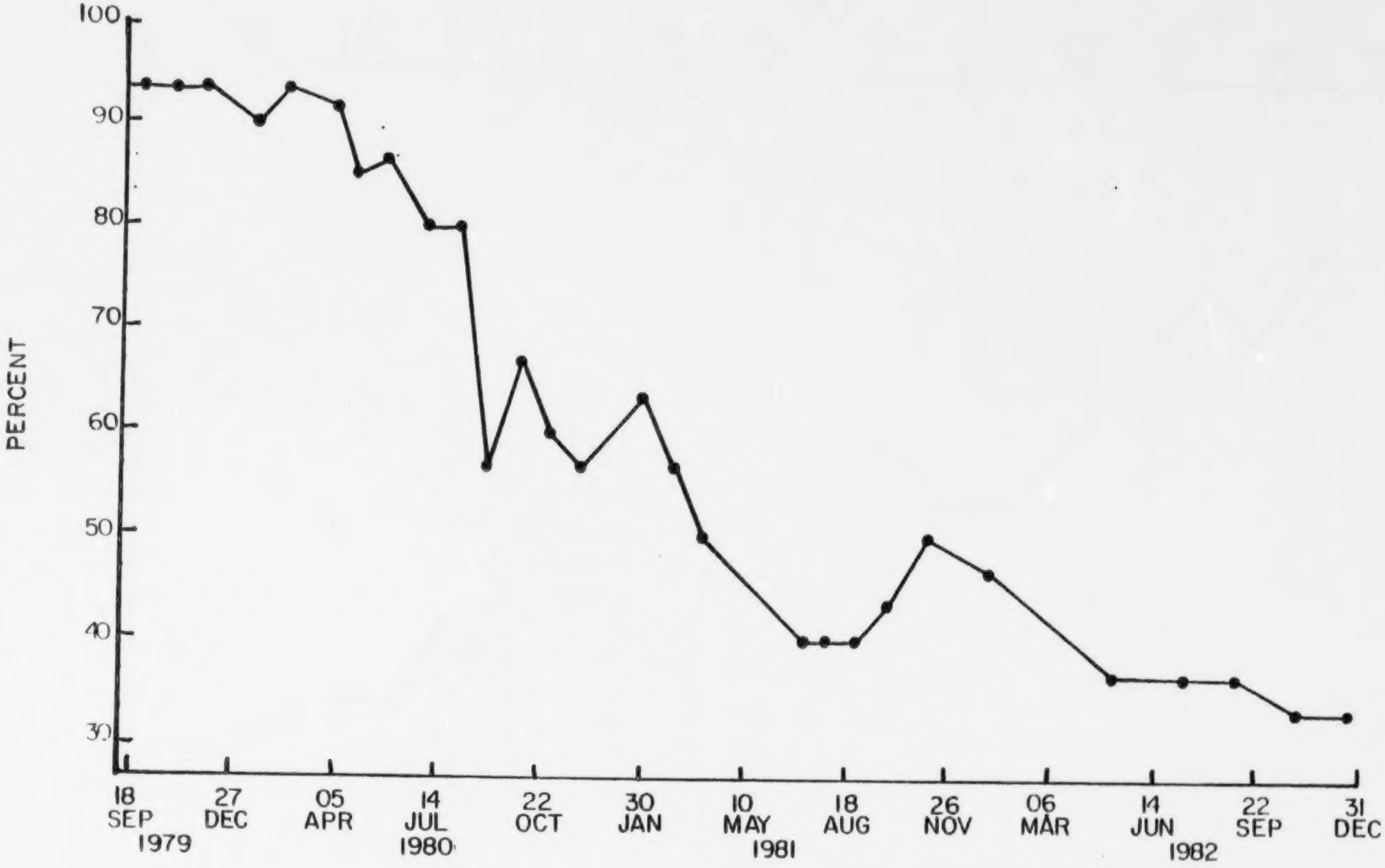

Figure 17. Percent vegetation remaining in 60% control grass carp ponds, Welaka, Florida.

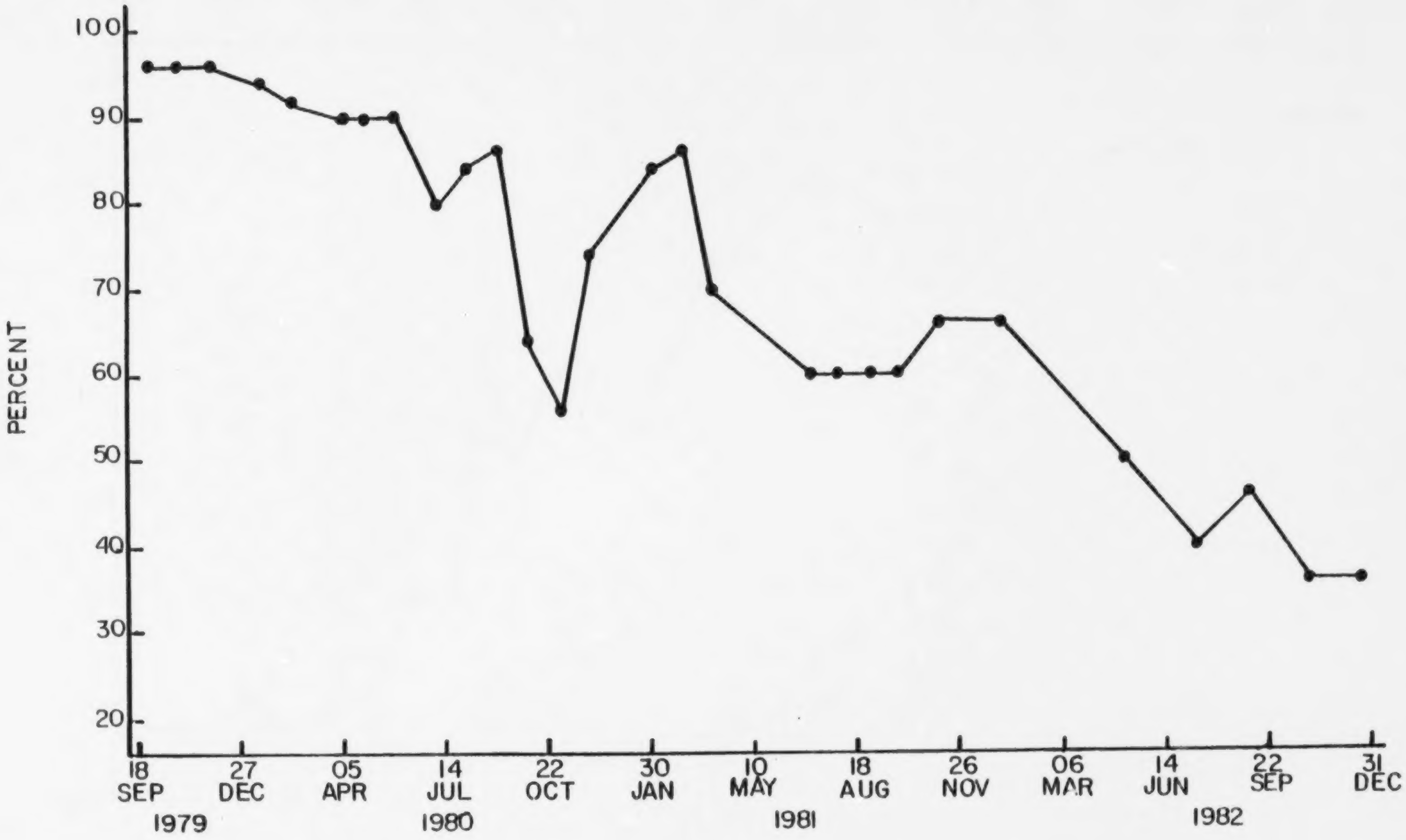

Figure 18. Percent vegetation remaining in 30% control grass carp ponds, Welaka, Florida.

Table 13. Application dates and the amount of herbicides used in Welaka ponds where vegetation is controlled chemically.

	5-16-80			6-30-80							3-16-80		4-14-80				
Pond	Hydout	Aqua-Kleen (kg)	Roundup (L)	Hydout (kg)	Aqua-Kleen (kg)	Roundup (L)	Hydout (kg) 9-12-80	Hydout (kg) 10-3-80	Hydout (kg) 10-14-80	Hydout (kg) 10-16-80	Hydout (kg)	Aqua-Kleen (kg)	Diquat (L)	Aqua-Kleen (kg)	Roundup (L)	Diquat (L) 5-27-81	Diquat (L) 6-17-81
2	2	5	2.5	-	5	4.0	1	-	-	2	1	4	0.5	6	4.0	-	-
4	-	5	2.0	-	-	1.0	-	-	-	1	1	2.5	0.5	6	3.0	-	-
5	1	5	1.0	-	-	4.0	-	-	-	-	-	-	0.5	3	3.0	-	-
6	2	5	0.5	-	-	3.0	-	-	-	-	-	3	-	4	4.0	-	-
9	2	5	3.5	2	-	2.0	-	-	-	2	3	3	4.0	6	3.0	4	-
11	2	5	1.5	2	-	6.0	1	-	-	2	3	3	4.0	6	7.0	4	4.0
18	2	-	1.0	2	-	3.0	2	-	-	4	5	-	1.0	-	-	2	*
21	2	-	3.0	2	-	2.0	2	-	1	1	3	-	0.5	-	6.0	1	-
24	2	-	2.0	3	-	0.5	2	2	1	4	3	-	4.0	-	1.5	4	4.0

Table 13 Continued.

	7-30-81				7-30-82			10-22-82		12-24-82
Pond	Diquat (L)	Hydout (kg)	Aqua-Kleen (kg)	Cutrine (L)	Diquat (L)	Hydout (kg)	Cutrine (L)	Diquat (L)	Cutrine (L)	Aqua-Kleen (kg)
2	-	-	10	-	-	-	-	1	2	13.1
4	-	5	7	-	-	-	-	2	4	13.1
5	-	-	-	-	-	-	-	3	6	18.2
6	-	-	-	-	-	-	-	-	-	-
9	4.0	-	8	6.0	4	-	8	4	10	22.7
11	4.0	-	8	4.0	4	-	8	2	4	22.7
18	*	*	*	*	*	*	*	*	*	*
21	-	5	-	-	-	8.5	-	1	-	-
24	4.0	-	-	10.0	8.5	-	8	4	10	-

In ponds where 100% hydrilla control was achieved, muskgrass (*Chara* *sp.*) and other filamentous algae increased. Chelated copper (mixed triethanolamine complexes) was used for their control.

In the 100% herbicide ponds, target vegetation levels were achieved in August 1981 and maintained with slight fluctuations through December 1982 (Figure 19). Hydrilla in ponds 9, 11 and 24 was effectively removed. Removal, however, resulted in the establishment of native submersed aquatic plants. In ponds 9 and 11, spikerush and bladderwort replaced hydrilla and required herbicide treatment. During the latter phases of the study, muskgrass (*Chara* *sp.*) also required treatment. In pond 9, watershield (*Brasiena* *schreberi*) invaded the pond during Summer 1982 and was treated and fragrant water lily abundance increased in pond 11 and required treatment. Muskgrass, spikerush and arrowhead then became established in this pond and were treated as needed.

Sixty percent vegetation removal was reached in the treatment ponds during August 1981 (Figure 20). Plant regrowth, however, occurred after August 1981 and levels were maintained slightly above the 30-40% control levels as additional treatment might have caused complete vegetation removal. Ponds 4 and 6 in this group required little treatment to manage hydrilla (Table 13) and other submersed plants. Pond 21, a shallow pond, required constant herbicide application to control hydrilla because of rapid regrowth rates.

In the 30% vegetation managment ponds, management levels were attained by July 1980 and remained between 30 and 50% through the remainder of the study (Figure 21). The submersed vegetation in the ponds in this series responded well to herbicide treatment. Only in pond 2 did fragrant water lily require frequent treatment (Table 13).

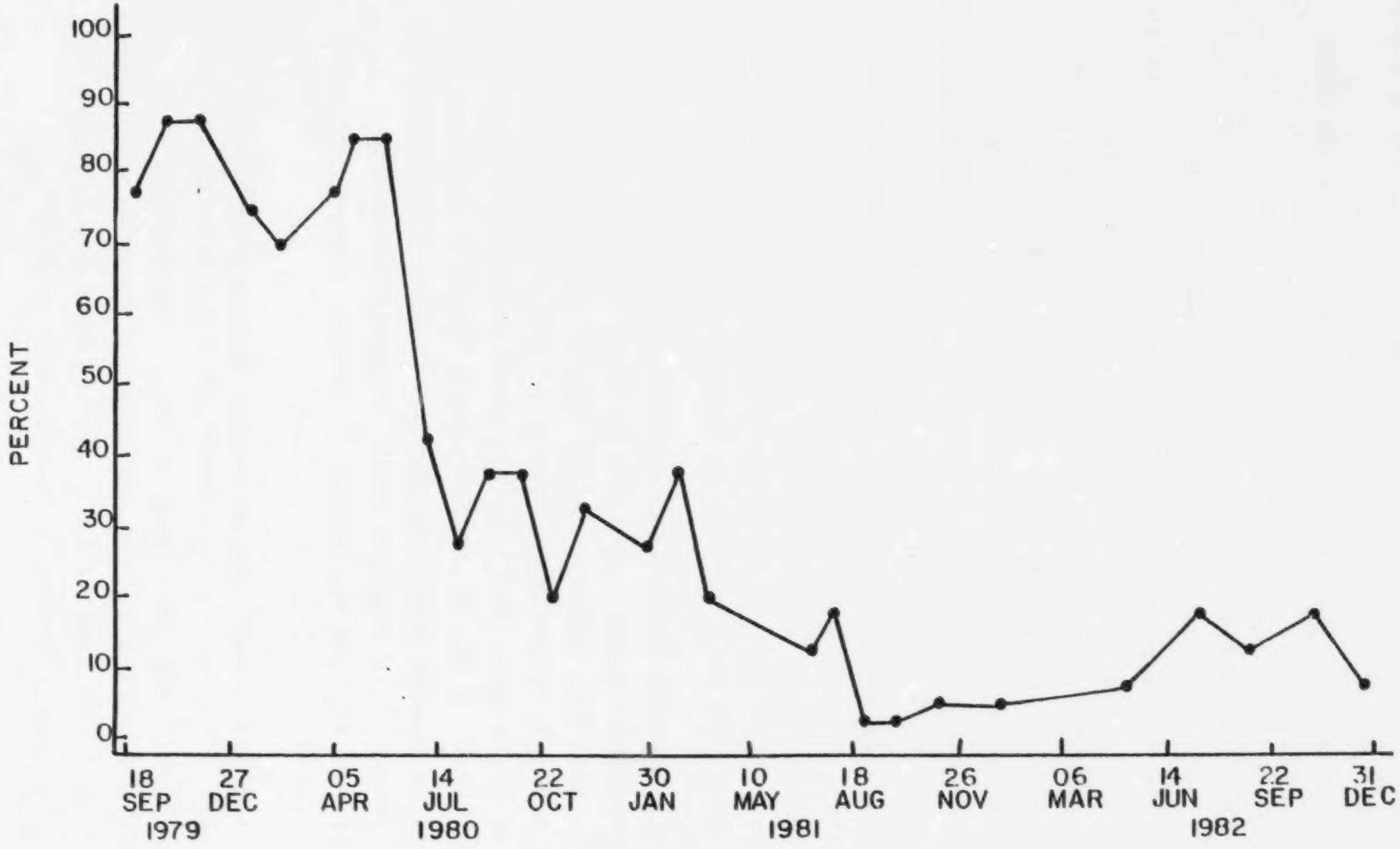

Figure 19. Percent vegetation remaining in 100% herbicide control ponds., Welaka, Florida.

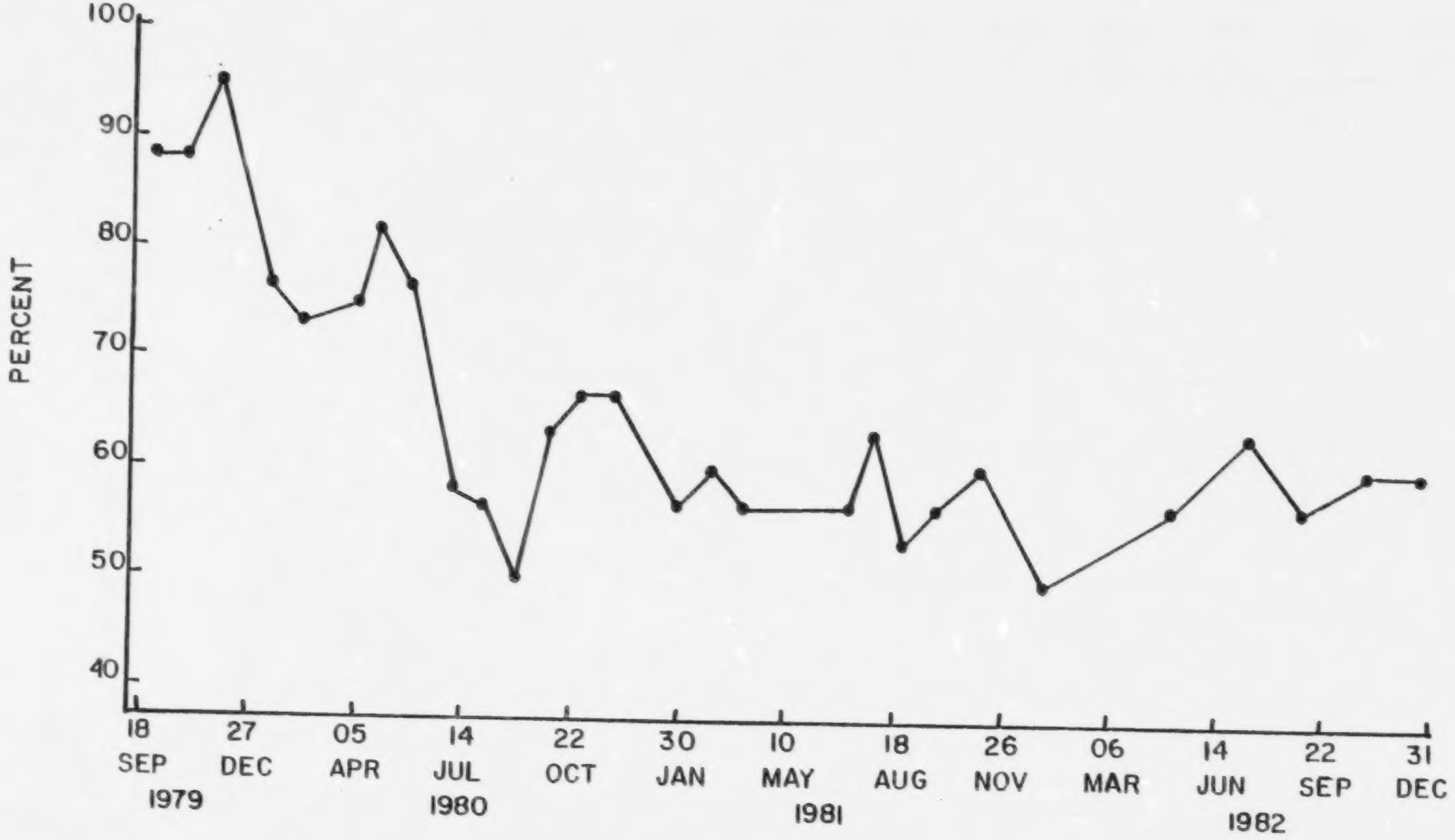

Figure 20. Percent vegetation reamining in 60% herbicide control ponds, Welaka, Florida.

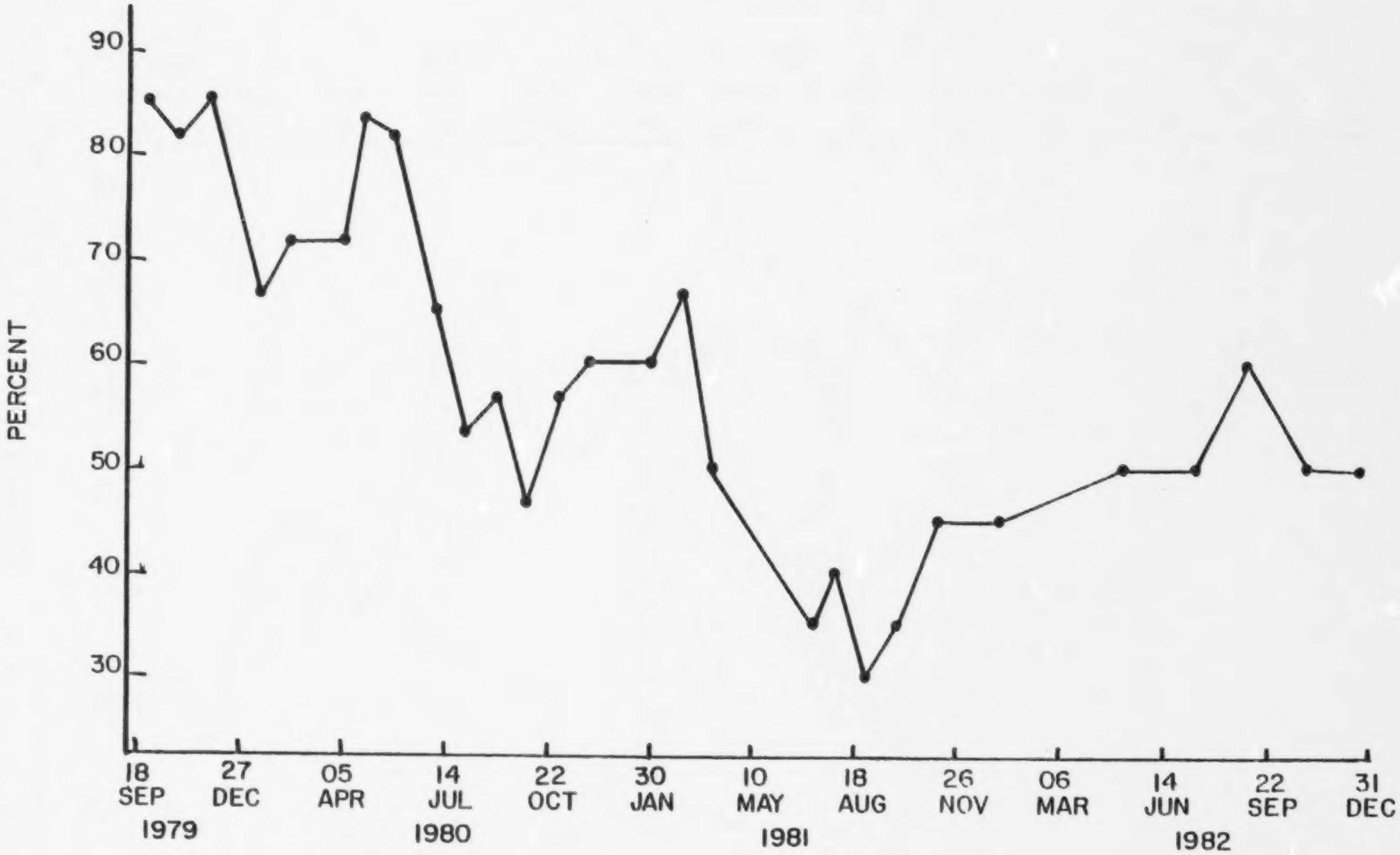

Figure 21. Percent vegetation remaining in 30% herbicide control ponds, Welaka, Florida.

A fertilization program was initiated during Spring 1979 to stimulate phytoplankton growth in order to inhibit macrophyte growth (Table 14). This treatment was not successful as macrophytes increased in these ponds from a low in December 1979 (Figure 22). During 1980, mechanical harvesting was used along with the fertilization program (Table 15). Fertilization and mowing was continued until December 1982. Even though fertilization caused phytoplankton blooms, these blooms were temporary and when they disappeared macrophyte growth increased. Failure to control submersed vegetation with fertilizers suggests that macrophyte communities in shallow ponds can dominate the vegetation community even under high nutrient loading. The growth of plants also indicates that mechanical harvesting would have to be used frequently. The cost of frequent harvesting, however, is costly. Mechanical harvesting also contributed to the spread of hydrilla in the fertilization ponds as it became the dominant macrophyte in two of these ponds.

The control ponds (100% vegetation) have remained full of vegetation. Only during two periods did the mean vegetation volume fall below 90% (Figure 23).

Water Quality

Lake Pearl

Lake Pearl is located on the Osceola Plain physiographic division, which is a broad flat plain extending from Seminole County to Okeechobee County (White 1970). In the northern section of the plain around Lake Pearl, however, remnant hills containing phosphatic sands are separated by poorly drained lowlands that connect numerous lakes. Surface geology is largely dominated by peats, muds, and nutrient-rich estuarine sediments (Puri and Vernon 1964). Canfield (1981) sampled 15 lakes located on the Osceola Plain during a statewide limnological survey that was designed to determine the chemical and trophic state characteristics of Florida lakes in relation to

Table 14. Amount of fertilizer and application dates for fish management ponds.

		Fertilizer (kg)			
Ponds	Date	10-10-10	0-20-0	35-0-0	dolomite
3,10,20	4-16-79	-	6.0	-	11.4
3,10,20	4-26-79	-	6.0	-	11.4
3,10,20	5-3-79	-	6.0	-	-
3,10,20	7-5-79	6.0	3.0	-	11.4
3,10,20	10-10-79	6.0	3.0	-	-
3,10,20	4-17-79	45.5	-	-	22.7
3,10	4-30-79	18.2	18.2	-	11.4
20	5-2-80	12.3	12.3	-	-
3,10	5-14-80	-	18.2		-
20	5-14-80	-	9.1		-
3,10,20	5-29-80	-	-	11.4	-
3,10	7-11-80	-	18.2	18.2	-
3,10,20	9-11-80	18.2	-	-	-
3,10,20	3-31-81	-	18.2	18.2	-
3,10,20	7-30-82	91.0	-	-	-
3,10,20	10-22-82	22.5	-	-	-

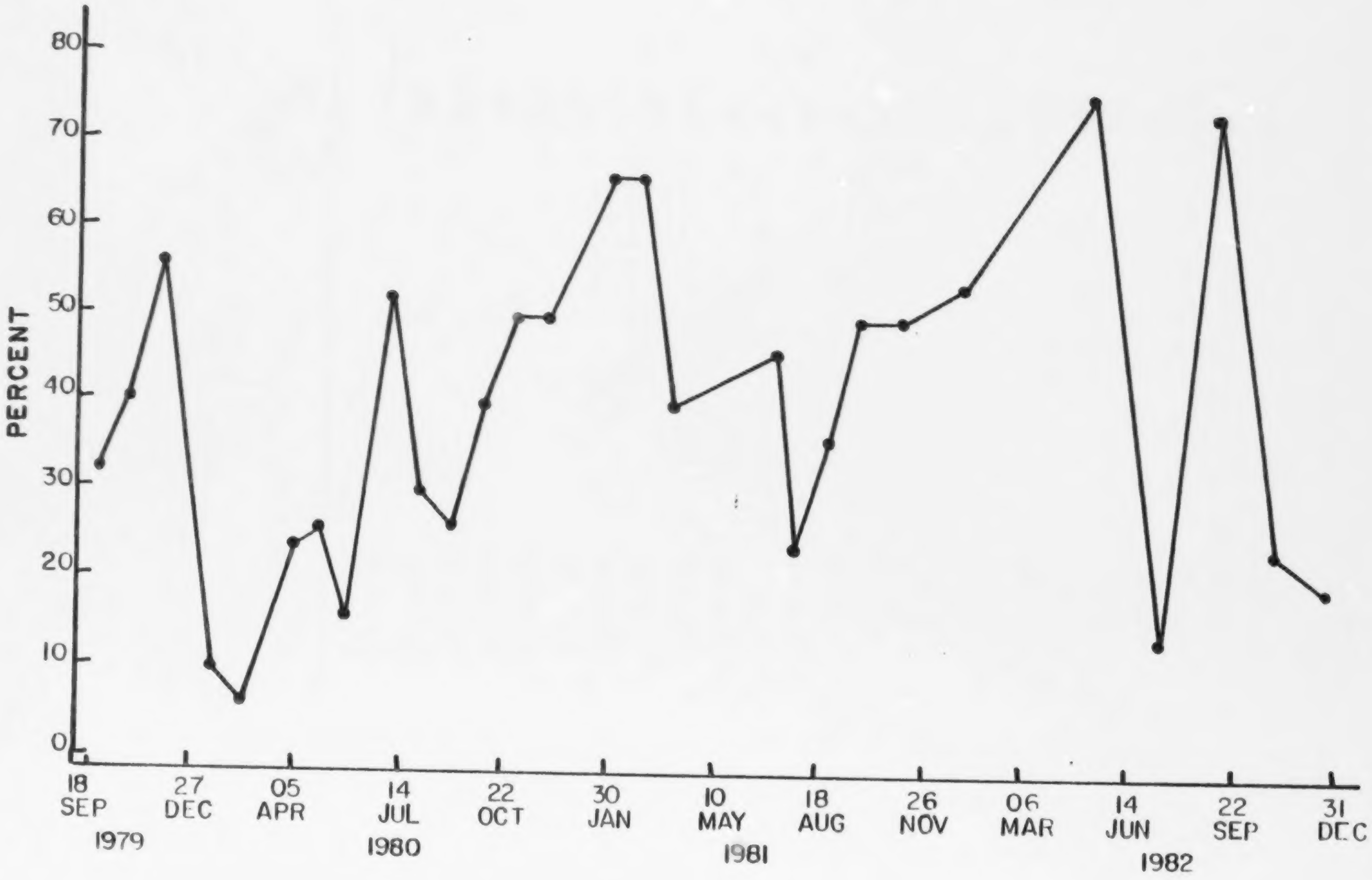

Figure 22. Percent vegetation remaining in fertilizer ponds, Welaka, Florida.

Table 15. Dates of mowing and vegetation removal for fish management ponds.

Pond	Mowing Date	Vegetation Removal
3	1-15-80	No
10	1-15-80	No
3	5-16-80	No
10	5-16-80	NO
3	7-9-80	YES
10	7-9-80	YES
3	8-27-80	YES
3	9-8-80	YES
10	9-8-80	YES
3	3-30-81	NO
10	3-31-81	NO
20	3-31-81	NO
3	7-21-81	NO
10	7-21-81	NO
20	7-22-81	NO
3	7-14-82	YES
10	7-15-82	YES
20	7-15-82	YES
3	10-11-82	YES
10	10-12-82	YES
20	10-12-82	YES
3	12-14-82	YES
10	12-16-82	YES
20	12-20-82	YES

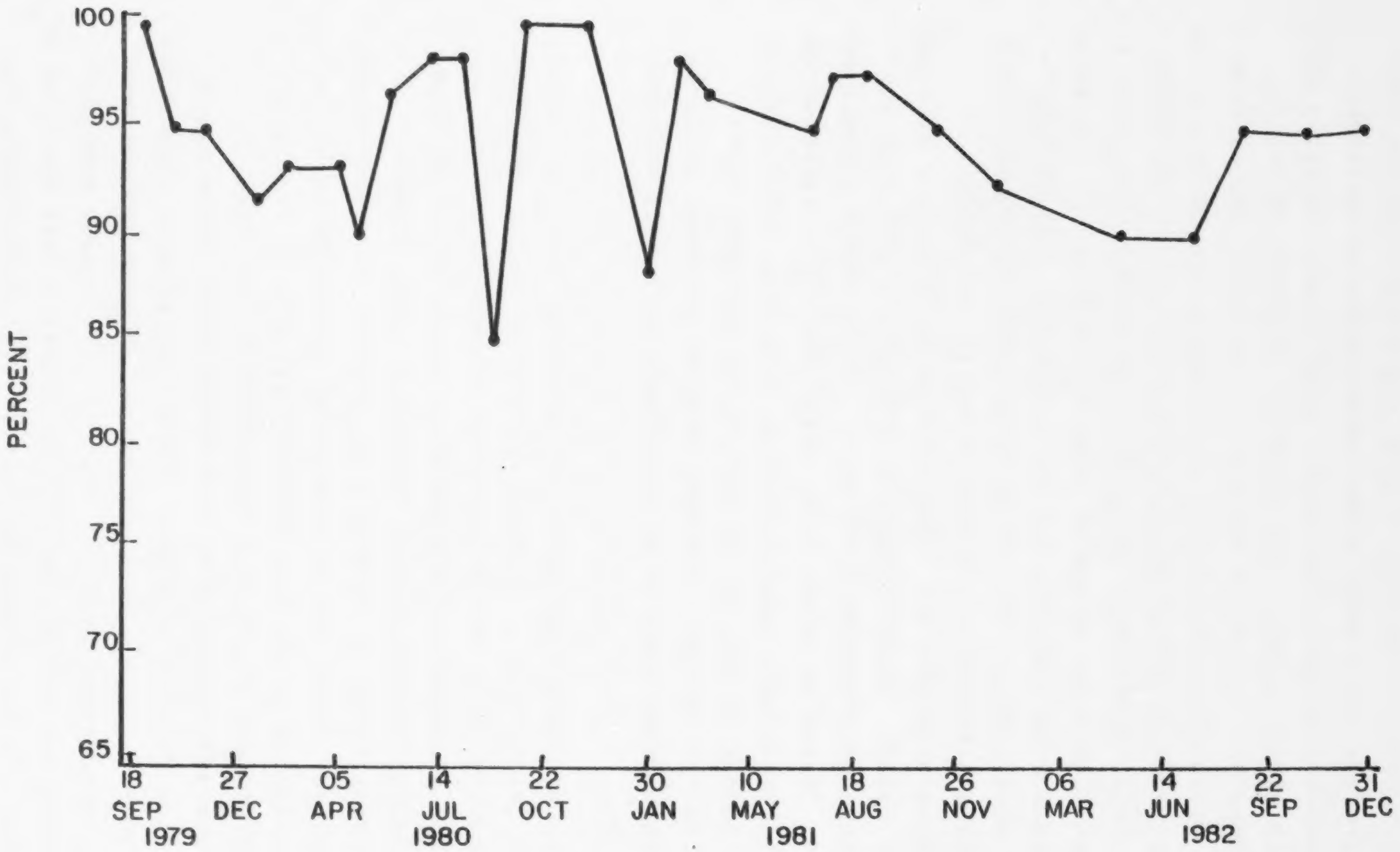

Figure 23. Percent vegetation in 100% vegetation ponds, Welaka, Florida.

regional geology. Canfield (1981) found that all the lakes on the Osceola Plain were either mesotrophic or eutrophic. Water quality, however, was found to be highly variable both among and within lakes. For example, regional pH values ranged from 4.3 to over 9 and total alkalinity ranged from 0 to 64 mg/l as $CaCO_3$. Specific conductance ranged from 64 to 235 umhos/cm and color values ranged from 20 to 250 Pt-Co units. Total phosphorus concentrations ranged from 0.006 to 0.311 mg/l and total nitrogen ranged from 0.438 to 2.6 mg/l. Chlorophyll a ranged from 0.5 to 137 mg/m^3. During the present study (Table 16), pH in Lake Pearl averaged 7.1 and bicarbonate alkalinity averaged 27 mg/l. Specific conductance averaged 165 umhos/cm and color values averaged 30 Pt-Co units. Total phosphorus averaged 0.028 mg/l and total nitrogen averaged 0.743 mg/l. Chlorophyll a averaged 12 mg/m^3. Based on these data, Lake Pearl is classified as a slightly alkaline, meso-eutrophic lake with water quality that is generally similar to that found in other lakes located in the region. However, similar to other lakes in the region, water quality in Lake Pearl is highly variable (Table 16).

Average monthly pH values ranged from less than 6.5 to over 9.0 (Figure 24). Although no statistically significant relationships could be demonstrated between pH and macrophyte abundance, the highest pH values occurred when large amounts of macrophytic vegetation were present. Monthly variations in pH were also greater when macrophyte abundance was high. Major effects of herbicide or grass carp treatments on pH were either temporary or negligible until sufficient grass carp were stocked to reduce macrophyte abundance. With vegetation loss, there was a general lowering of lake pH. Values for pH were also found to fluctuate within a narrower range. The values, however, were not substantially lower than the low values measured when vegetation was present. This suggests that the loss of vegetation has not adversely lowered pH. Furthermore, the volume of water in Lake Pearl decreased from 56.0 x 10^4 m^3

Table 16. Mean, standard error, and range of water quality parameters measured in Lake Pearl between March 1979 and November 1982.

Parameter	Mean	Standard Error	Minimum	Maximum
pH	7.1	0.05	6.1	10.5
Carbon Dioxide (mg/l)	1.4	0.08	0	17
Bicarbonate (mg/l)	27	0.4	0	45
Carbonate (mg/l)	1.9	0.2	0	20
Specific Conductance (µmhos/cm at 25 C)	165	2	16	270
Calcium (mg/l)	16	0.2	6.4	24
Magnesium (mg/l)	5.9	0.05	0.7	8.1
Potassium (mg/l)	4.8	0.1	0.1	9.0
Orthophosphate (mg P/l)	0.003	0.0004	0	0.100
Total Phosphorus (mg P/l)	0.028	0.001	0.001	0.365
Total Nitrogen (mg N/l)	0.743	0.014	0.048	3.76
Turbidity (NTU)	3	0.1	0.3	28
Chlorophyll a (mg/m^3)	12	1	0.2	75
Pheophytin (mg/m^3)	2.3	0.2	0	28
Color (Pt-Co units)	30	0.6	6	88

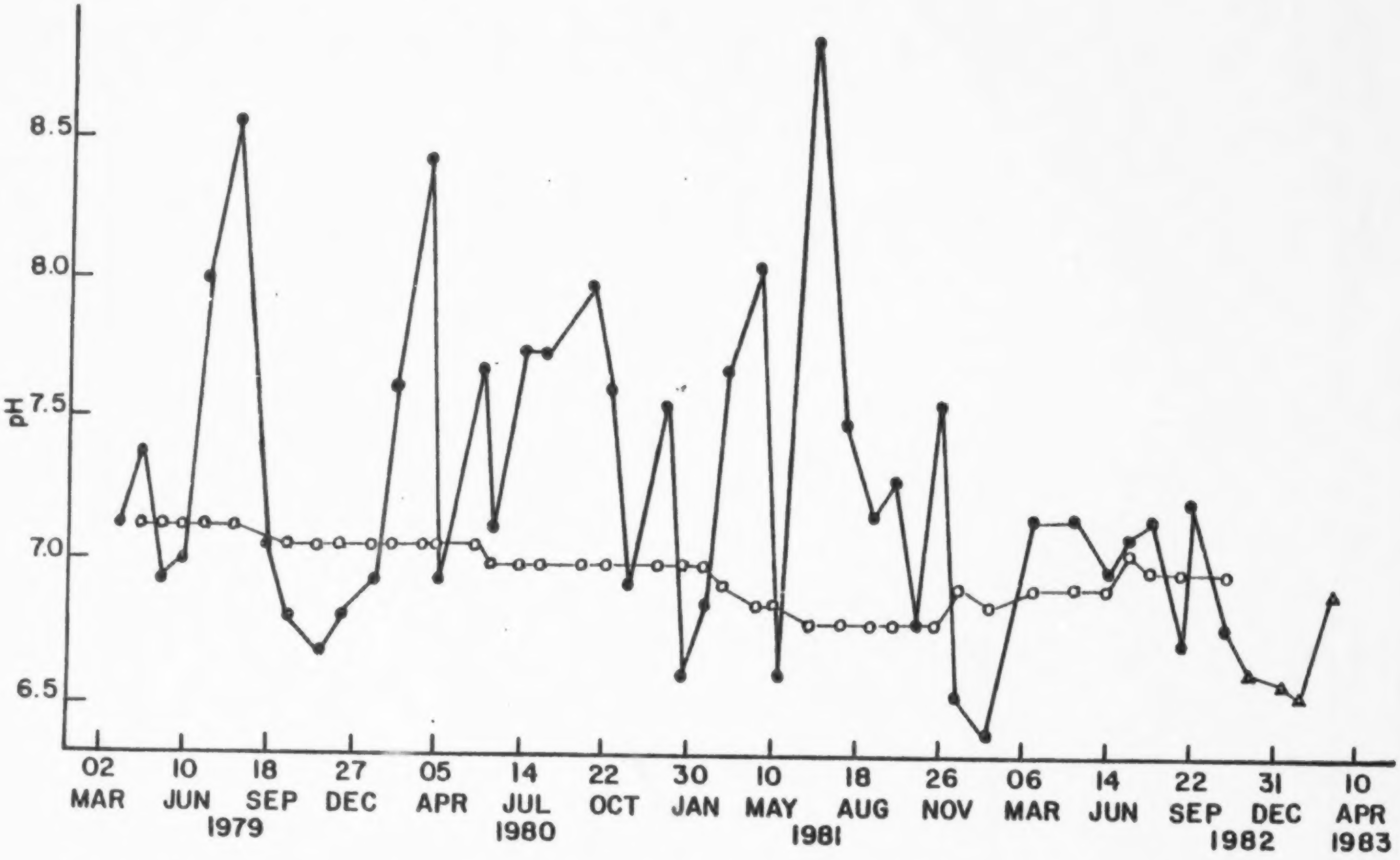

Figure 24. Changes in average pH concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

in 1979 to 25.1 x 10^4 m^3 in 1981, a 50% reduction (Table 17). After August 1981, lake volume increased to 40.4 x 10^4 m^3. To assess the effect of changes in lake hydrology, predicted pH values were calculated from the first measured pH assuming only changes in lake volume (Figure 24). At the end of this study, measured pH values were in good agreement with the predicted values, indicating that pH values are not significantly lower than expected when changes in lake hydrology are considered.

Average monthly carbon dioxide concentrations ranged from 0 to 4.0 mg/l (Figure 25). Changes in carbon dioxide concentrations, however, were not related to either changes in macrophyte abundance or the implementation of various management treatments. Predicted carbon dioxide concentrations also did not agree with the measured concentrations. However, predicted concentrations were calculated assuming only concentration and dilution. The lowest concentrations of carbon dioxide occurred during periods of low water whereas the higher concentrations occurred when water levels were high or increasing. If in-lake concentrations are dependent on carbon dioxide inputs from the watershed, or inputs of materials that contribute to carbon dioxide levels, then the lower concentrations might be the result of a combination of depletion by aquatic plants and lack of replenishment from the watershed.

Mean monthly bicarbonate concentrations ranged from less than 12 mg/l to more than 39 mg/l (Figure 26). Multiple regression analysis indicated changes in lake volume and percent of the lake's total volume infested with submersed macrophytes account for 58% of the observed variance in bicarbonate concentrations. As lake volumes decreased, there was a general rise in bicarbonate concentrations. Concentrations decreased as the lake's volume increased. Reduced bicarbonate concentrations also generally occurred when macrophyte abundance (expressed as the percent of the lake's total volume infested) was high.

Table 17. Lake Pearl water volume, 1979-1982.

	1979 Lake Volume (m^3x 10^4)	1980 Lake Volume (m^3x 10^4)	1981 Lake Volume (m^3x 10^4)	1982 Lake Volume (m^3x 10^4)
January				33.8
February			38.9	31.2
March		47.3	37.6	30.2
April	56.0	47.3	34.0	33.0
May			31.2	33.0
June		47.3		
July			27.3	35.9
August		42.0	25.1	40.4
September			27.3	
October		40.4		40.4
November			27.3	
December		39.2	27.3	40.4

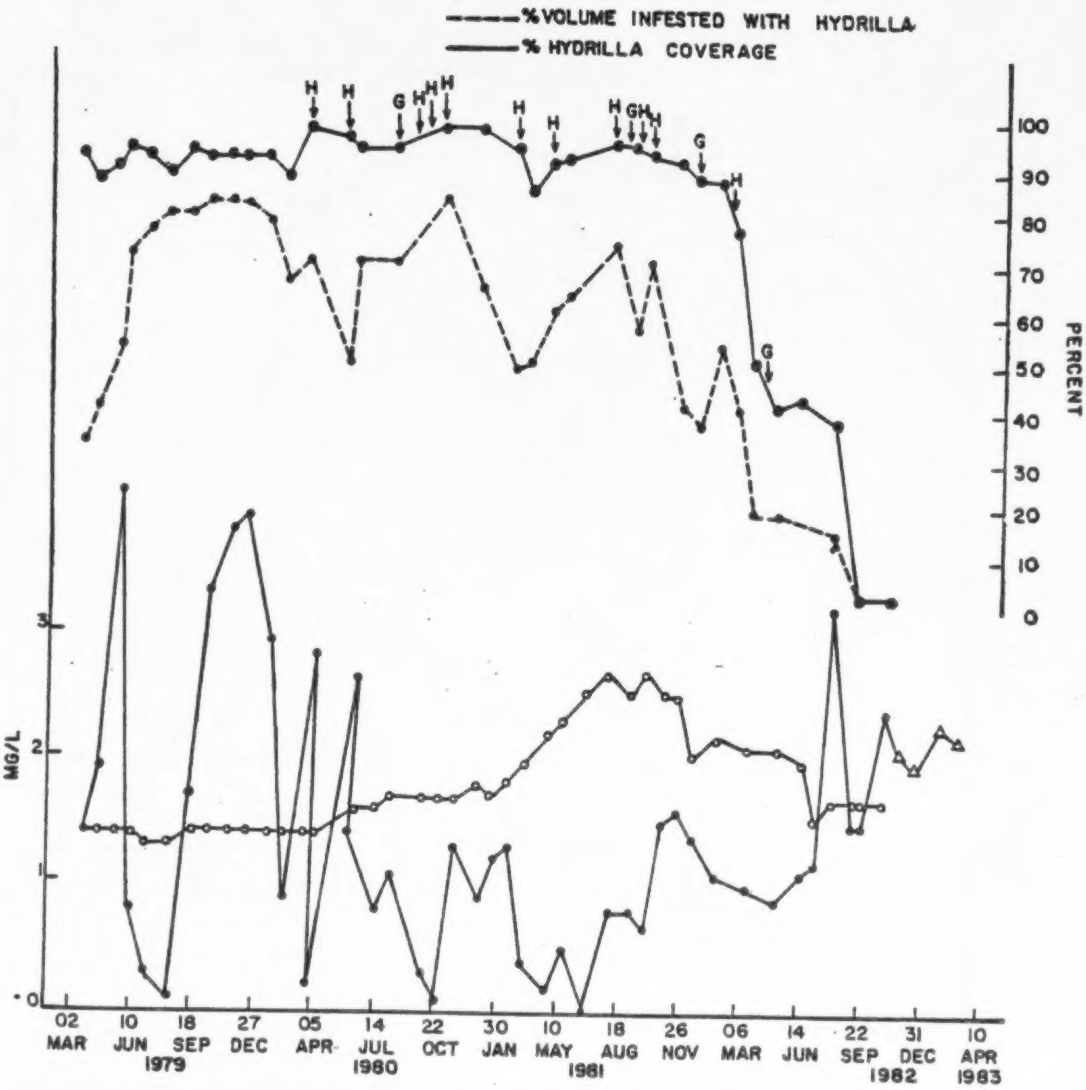

Figure 25. Changes in average carbon dioxide concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

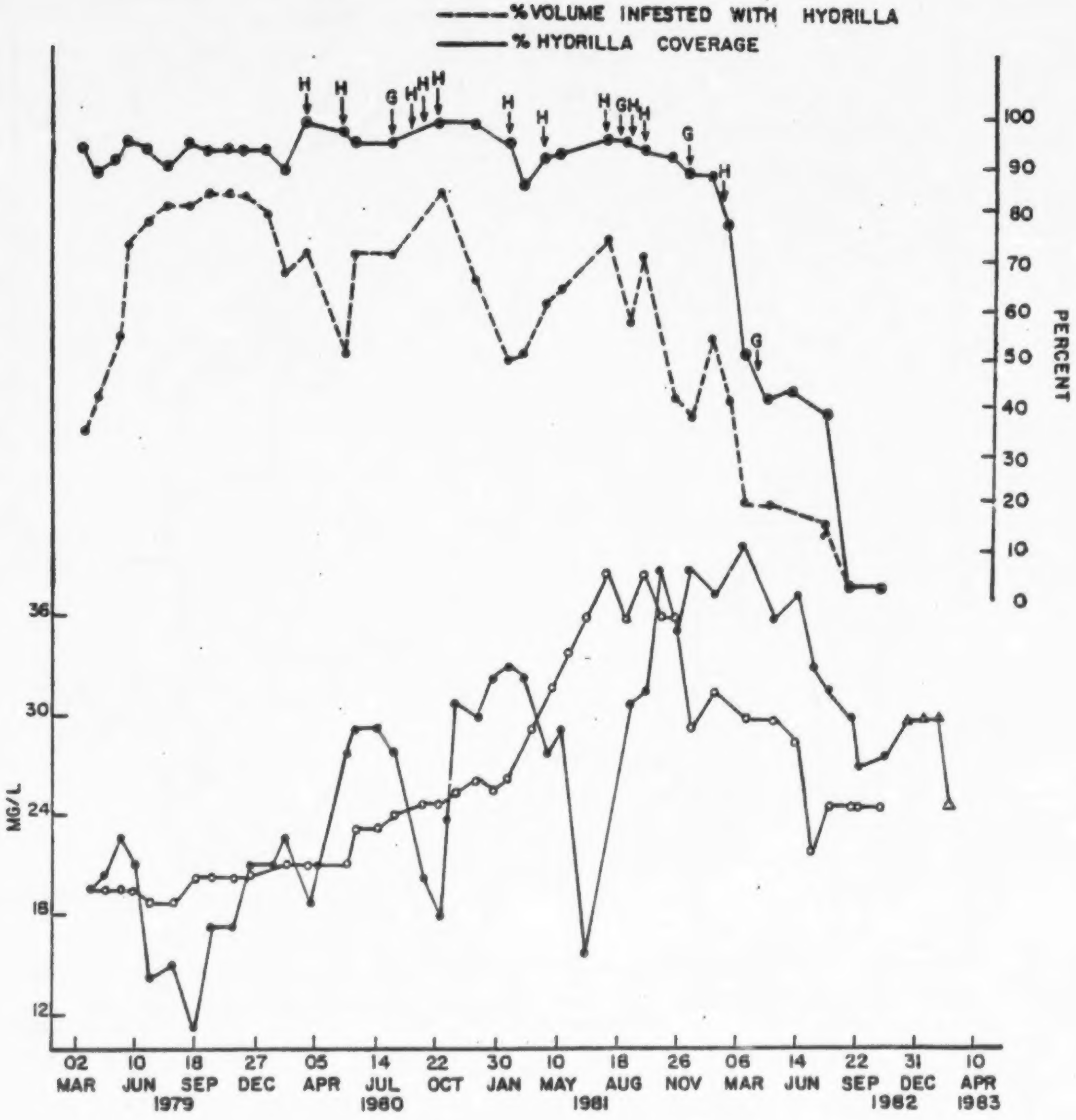

Figure 26. Changes in average bicarbonate concentration measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

Reductions in macrophyte abundance by either herbicides or grass carp generally resulted in increases in bicarbonate concentrations. These changes in concentrations most likely are the direct result of changes in plant photosynthetic activity.

Mean monthly carbonate concentrations ranged from 0 to over 12 mg/l (Figure 27). Similar to pH, the highest concentrations occurred when macrophyte abundance was high. Monthly variations were also greater. Reductions in macrophyte abundance (expressed as the percent of the lake's volume infested) by either herbicides or grass carp led to reductions in carbonate concentrations (Figure 27). Reductions, however, were temporary until sufficient grass carp were stocked to eliminate weeds. Once the percent volume infestation of weeds fell below 40%, carbonate concentrations were undetectable (Figure 27).

Average monthly specific conductance values ranged from 110 umhos/cm to 230 umhos/cm (Figure 28). Multiple regression analysis showed that changes in lake volume and percent volume infested with macrophytes accounted for 83% of the sample variance. Changes in lake volume accounted for over 95% of the explained variance. Consequently, there was good agreement between predicted specific conductance values and measured values (Figure 28). There were, however, significant effects caused by the macrophytes. A general trend of decreasing specific conductance was found as macrophyte abundance (expressed as the percent volume infested) increased. Decreases in macrophyte abundance caused by either herbicides or grass carp caused rises in specific conductance. Following vegetation removal by grass carp, specific conductance values generally remained higher than predicted values suggesting ions were released from the macrophytes to the overlying water or that plant photosynthesis was no longer causing the precipitation of ions such as calcium (Wetzel 1975).

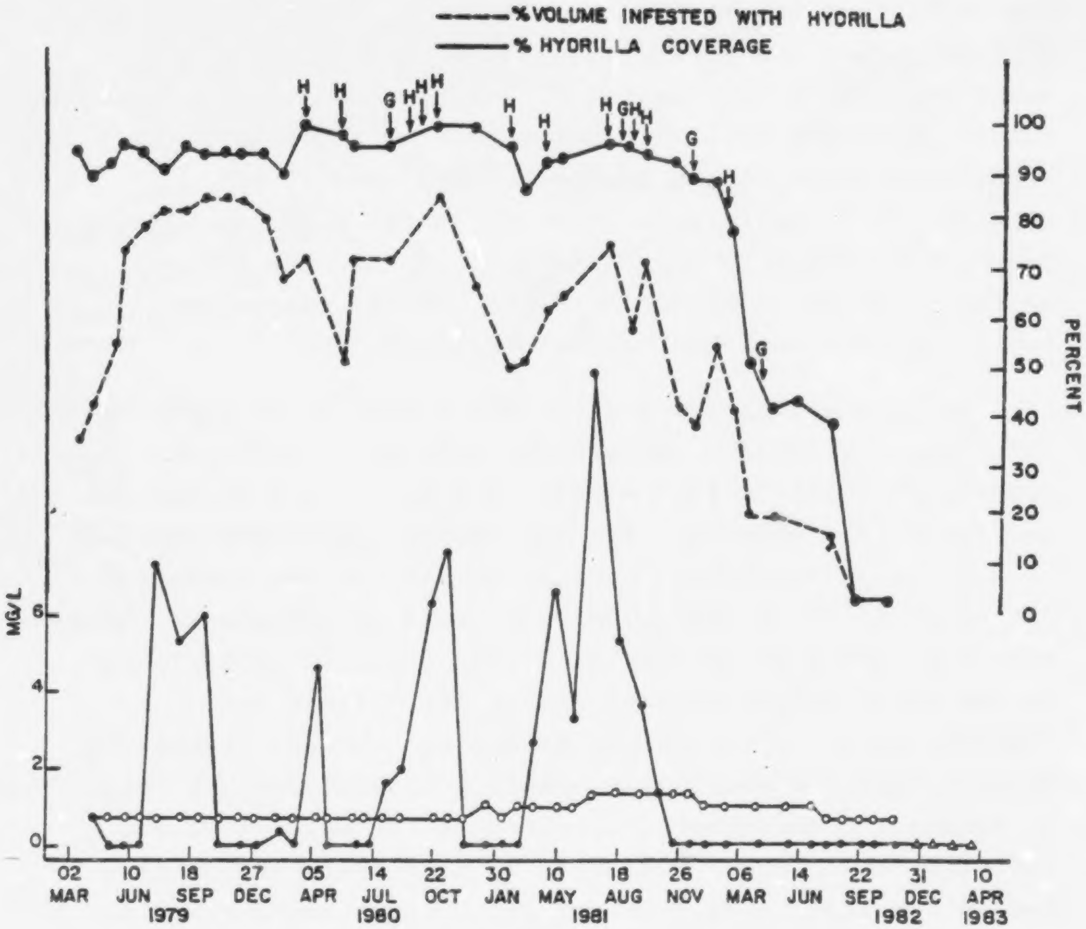

Figure 27. Changes in average carbonate concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

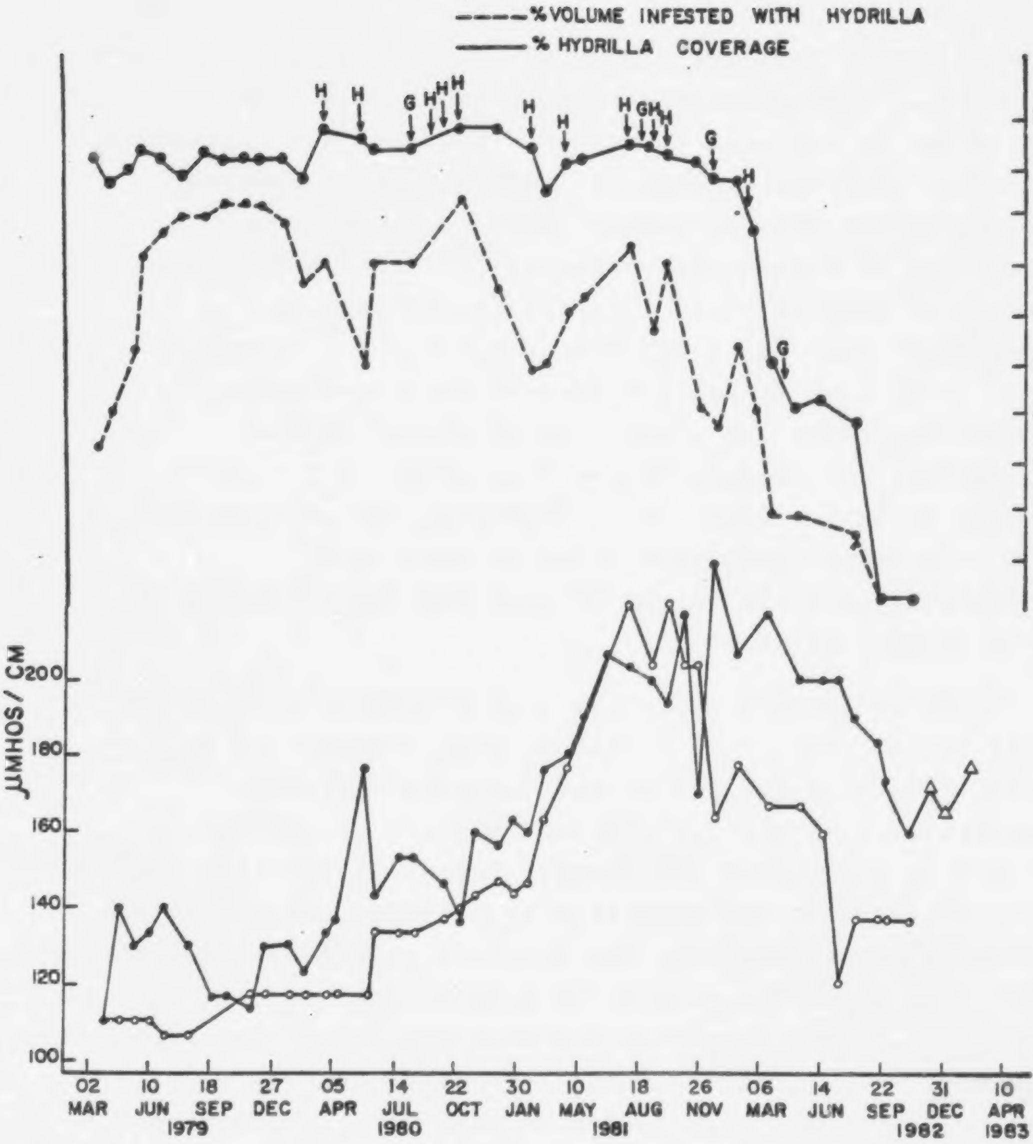

Figure 28. Changes in average conductivity values measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

Average monthly calcium concentrations ranged from less than 10 mg/l to over 22 mg/l (Figure 29). Similar to specific conductance, two factors, changes in lake volume and changes in percent volume infested with aquatic macrophytes, accounted for most of the variance ($R^2=0.78$). Calcium levels steadily increased as the volume of the lake decreased. Concentrations declined from peak values once the volume of the lake increased. Although the relationship was weak, there was a general trend for lower calcium concentrations when macrophyte abundance was high. Reductions in macrophyte abundance by either herbicides or grass carp generally led to increases in calcium concentrations. The increases, however, were temporary until sufficient grass carp were stocked to remove all vegetation. With the loss of vegetation, calcium concentrations remained higher than expected for given changes in lake volume. This suggests that calcium ions were released to overlying water or that plant photosynthesis is no longer causing the precipitation of large amounts of calcium.

Average monthly magnesium concentrations ranged from about 4.0 mg/l to 10 mg/l (Figure 30). Changes in lake volume accounted for 84% of the observed variance. Statistical analysis did not indicate any significant effects of macrophyte abundance. This suggests that changes in lake hydrology are primarily responsible for changes in magnesium concentrations, but measured values are generally lower than predicted values until macrophyte vegetation is eliminated. This suggests that macrophytes may be having some effects. Herbicides and grass carp treatments, however, generally have either no effect or a negligible effect on magnesium concentrations.

Monthly potassium concentrations ranged from less than 1 mg/l to over 8 mg/l (Figure 31). Changes in lake volume and the percent volume infested with macrophytes explained 80% of the observed variance. Fluctuations in lake volume

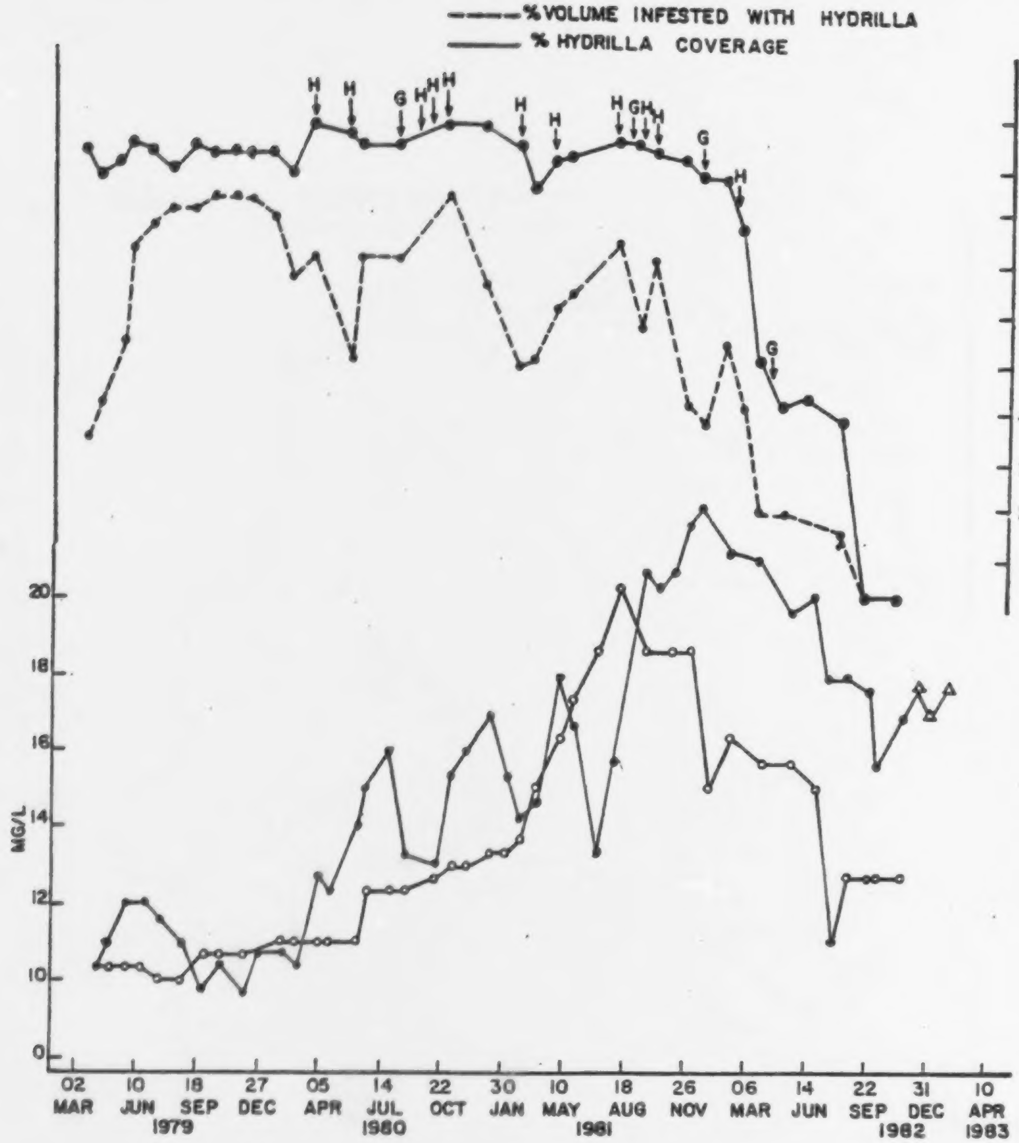

Figure 29. Changes in average calcium concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

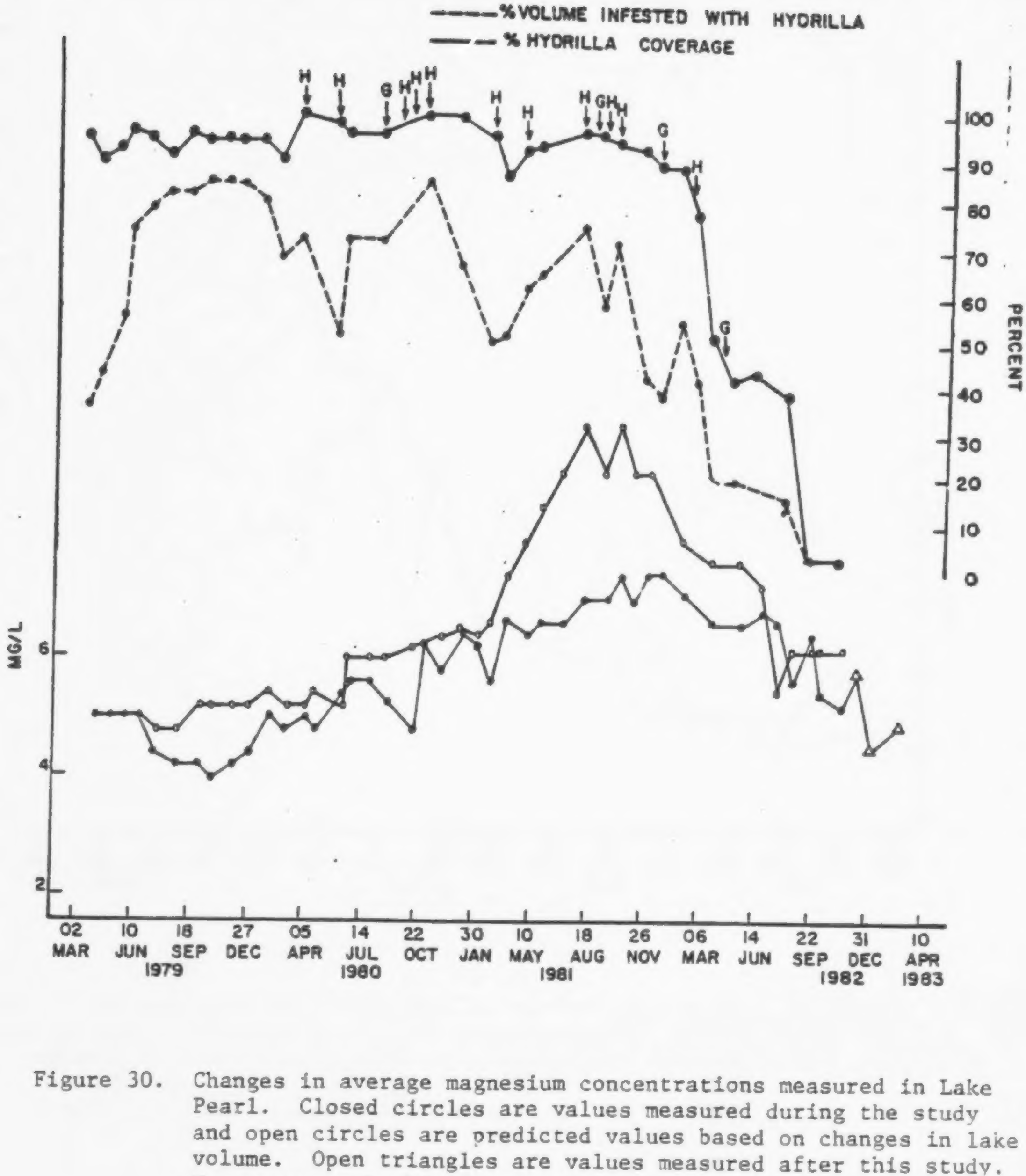

Figure 30. Changes in average magnesium concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

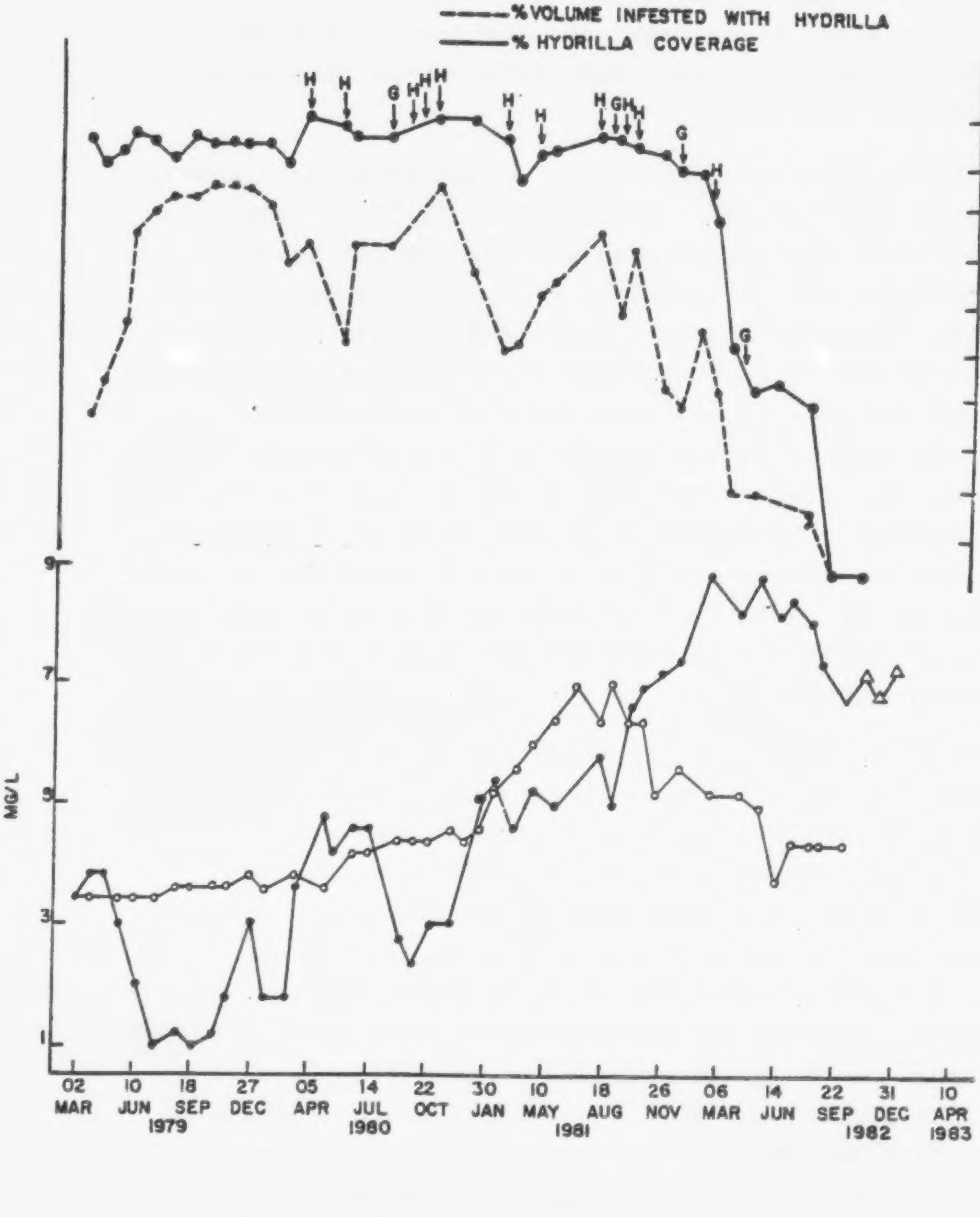

Figure 31. Changes in average potassium concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

accounted for 63% of the explained variance. Potassium concentrations, however, were low when macrophyte abundance expressed as a percent of the lake's total volume infested with macrophytes was high. Reductions in macrophyte abundance by herbicides or grass carp caused increases in potassium levels. These increases are most likely the result of potassium releases from macrophytes (Avault et al. 1968, Lembi et al. 1978).

Total nitrogen concentrations ranged from approximately 0.4 mg/l to over 1.2 mg/l (Figure 32). Multiple regression analysis showed that changes in lake volume and percent volume infested with macrophytes accounted for only 39% of the sample variance. Approximately 84% of the variance explained by the regression model was due to changes in the percent of the lake volume infested with macrophytes. Nitrogen values were generally higher when macrophyte abundance, expressed as the percent of the lake's total volume infested with macrophytes, was below 50%. No major differences in response were observed for herbicide or grass carp treatments. With the loss of vegetation, nitrogen values have remained high, but are not higher than those found in other lakes in the region.

Average monthly orthophosphate concentrations ranged from 0 mg/l to over 0.03 mg/l (Figure 33). Statistical analyses indicated no significant effects due to macrophytes and only a small effect due to (R^2=0.14) changing lake volume. The highest orthophosphate concentration, however, coincided with the initial herbicide treatment which caused a major decline in the percent lake volume infested with macrophytes. Because the phytoplankton level was low during this period, the released orthophosphate may not have been used by phytoplankton. With the total loss of vegetation, however, orthophosphate concentration declined to zero. This decline in available phosphorus is probably due to uptake by phytoplankton and conversion into total phosphorus.

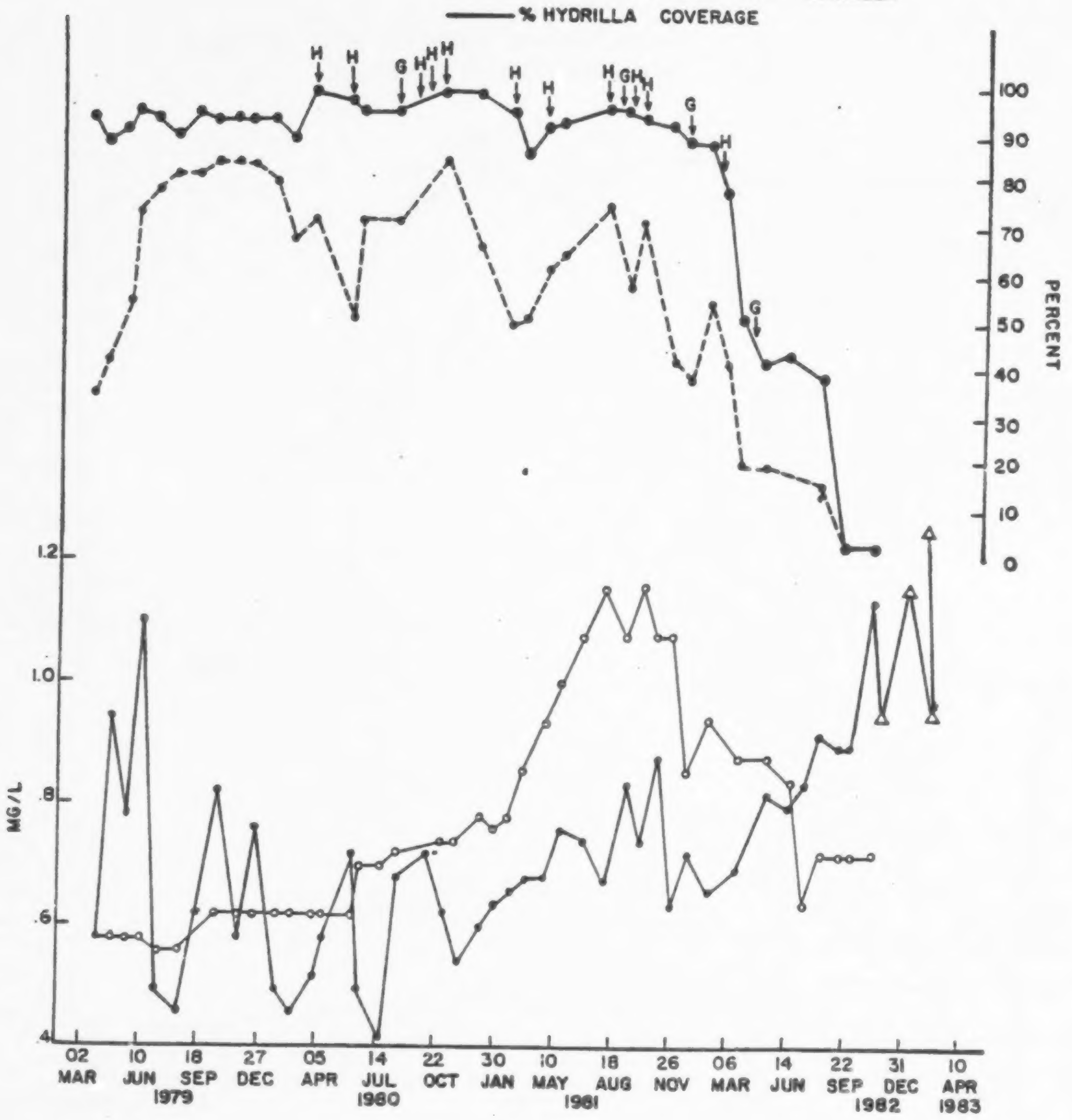

Figure 32. Changes in average nitrogen concentrations measured in Lake Pearl. Closed cirlces are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

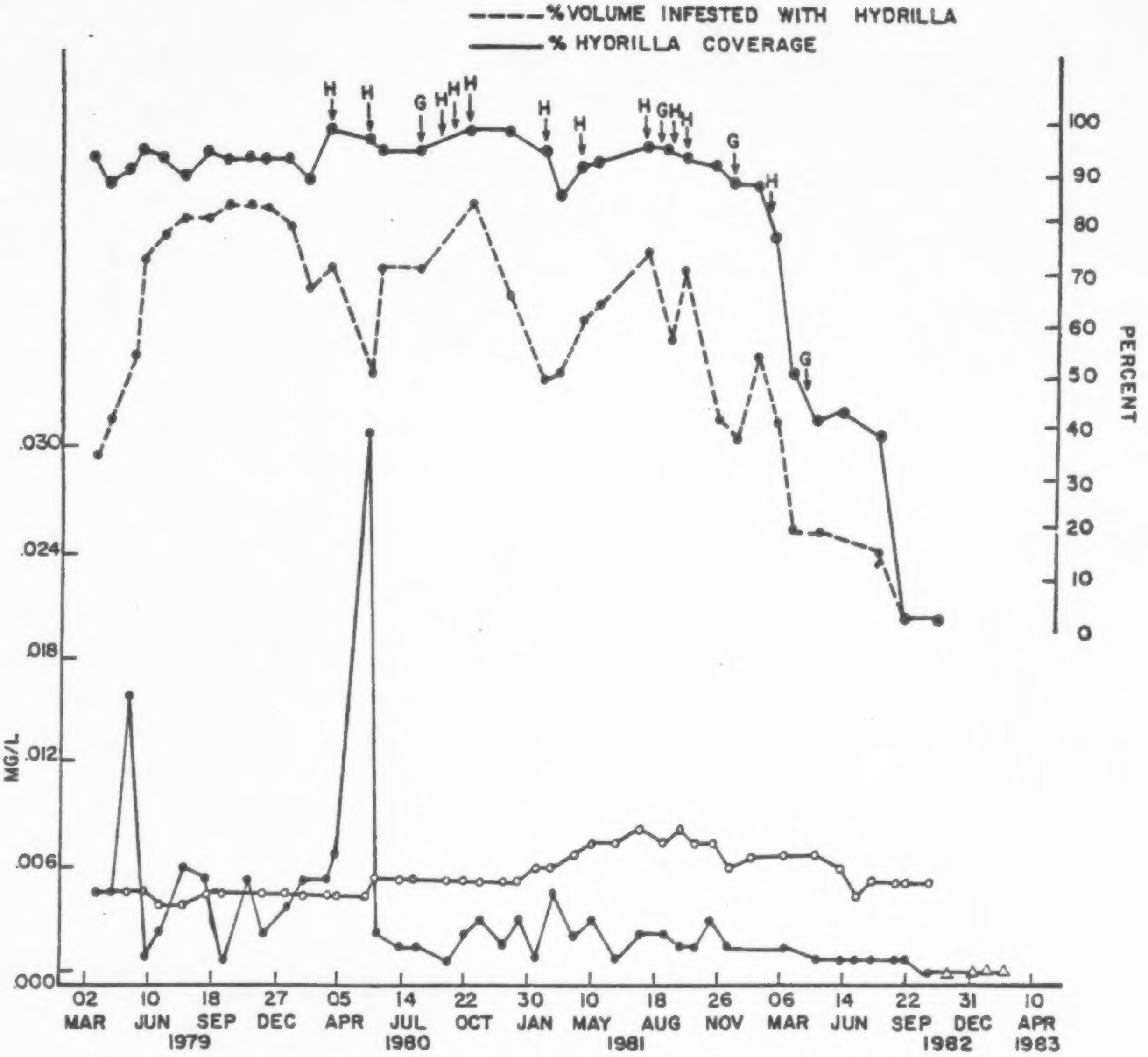

Figure 33. Changes in average orthophosphorus concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

Average monthly total phosphorus concentrations ranged from less than 0.01 mg/l to over 0.10 mg/l (Figure 34). Only 15% of the sample variance in total phosphorus concentrations was accounted for. All of this was due to changes in the percent of the lake's volume infested with macrophytes. A trend towards low total phosphorus concentrations with high macrophyte abundance was noted and higher total phosphorus concentrations generally occurred when macrophyte abundance was reduced. No major effects of herbicides or grass carp treatments, however, could be demonstrated.

Average monthly water color values ranged from less than 20 Pt-Co units to over 60 Pt-Co units (Figure 35). Low color values occurred during periods of high water. Color values were also generally lower when macrophyte abundance (% volume infested) was high. Changes in lake volume and macrophyte abundance accounted for 56% of the sample variance. High color values result from the input of colored water from surrounding swamps and from the decay of macrophytes in the lake. Although predicted color values indicate color should increase during periods of low water, intense sunlight can destroy color, thus color levels will be reduced unless inputs of colored water continue.

Mean monthly turbidity measurements ranged from less than 1 NTU to over 10 NTU. Peak turbidity measurements were primarily associated with reductions in vegetation abundance. Changes in the percent lake volume infested with macrophytes accounted for 51% of the observed variance. Similar responses were observed whether herbicides or grass carp caused the reductions in vegetation. The highest turbidity values occurred after grass carp were stocked in sufficient numbers to eliminate submersed vegetation. High values, however, were only temporary and decreased to levels observed when macrophytes were present. This suggests that the removal of vegetation by grass carp has not caused long term increases in turbidity levels (Figure 36).

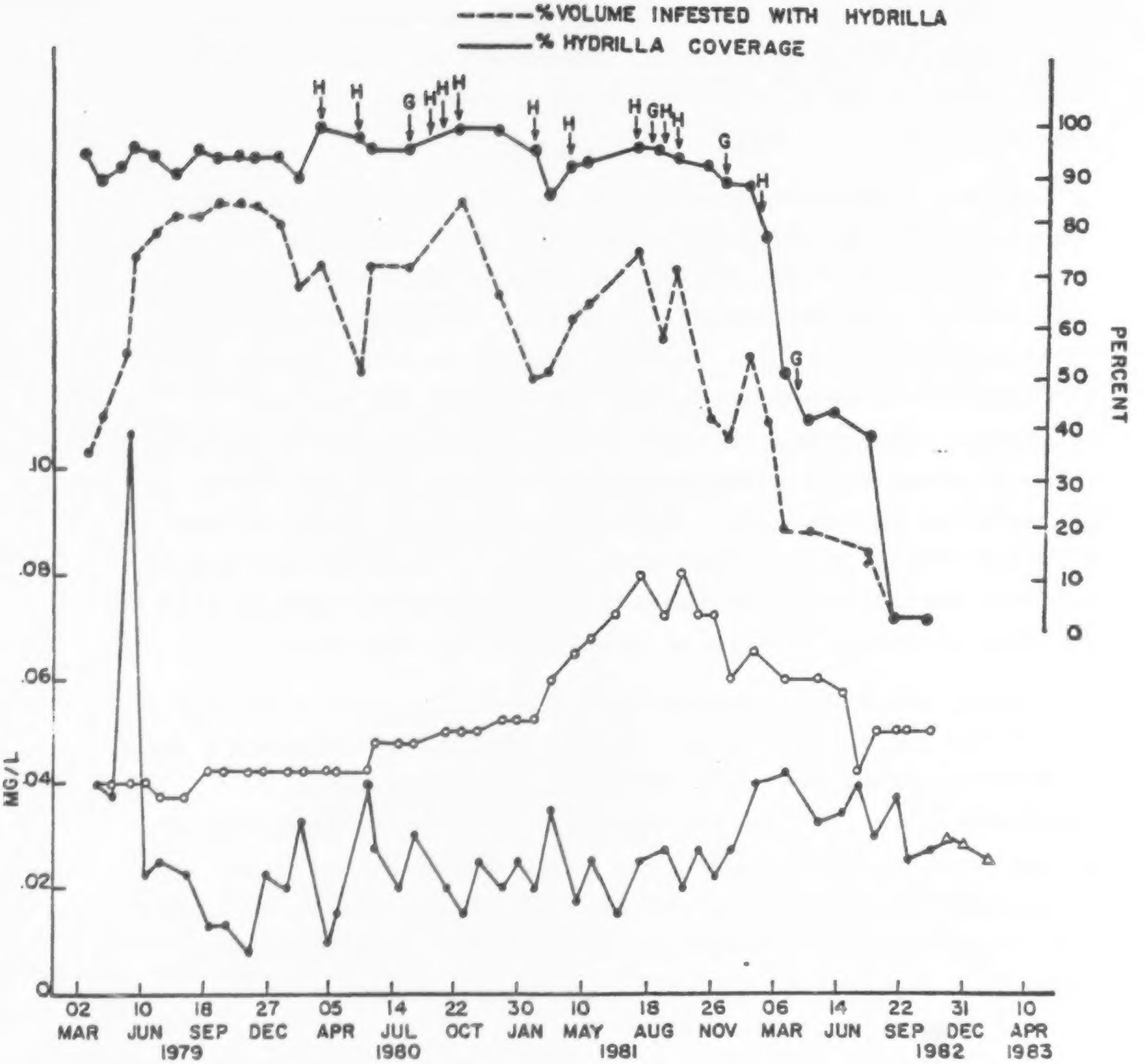

Figure 34. Changes in average total phosphorus concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

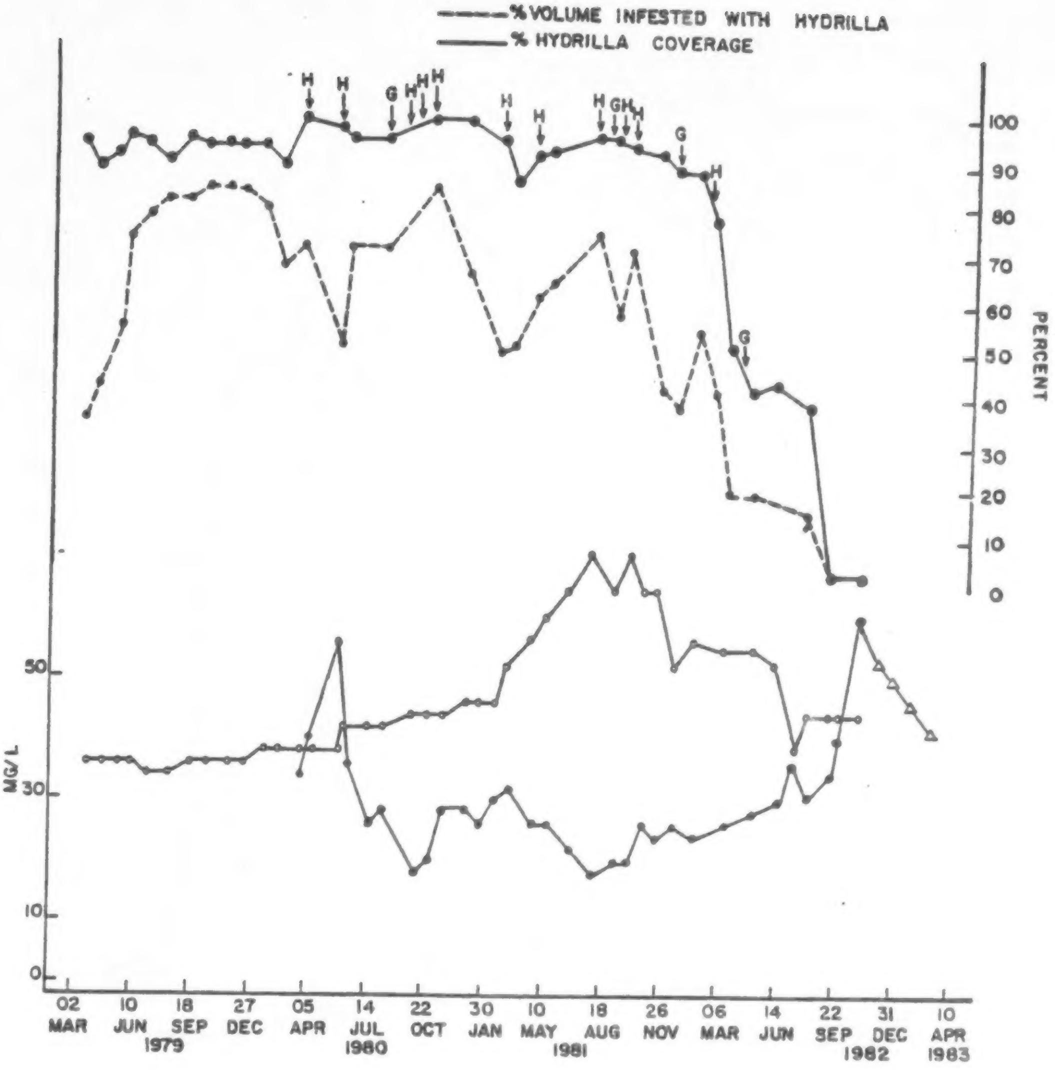

Figure 35. Changes in average color values measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stocking.

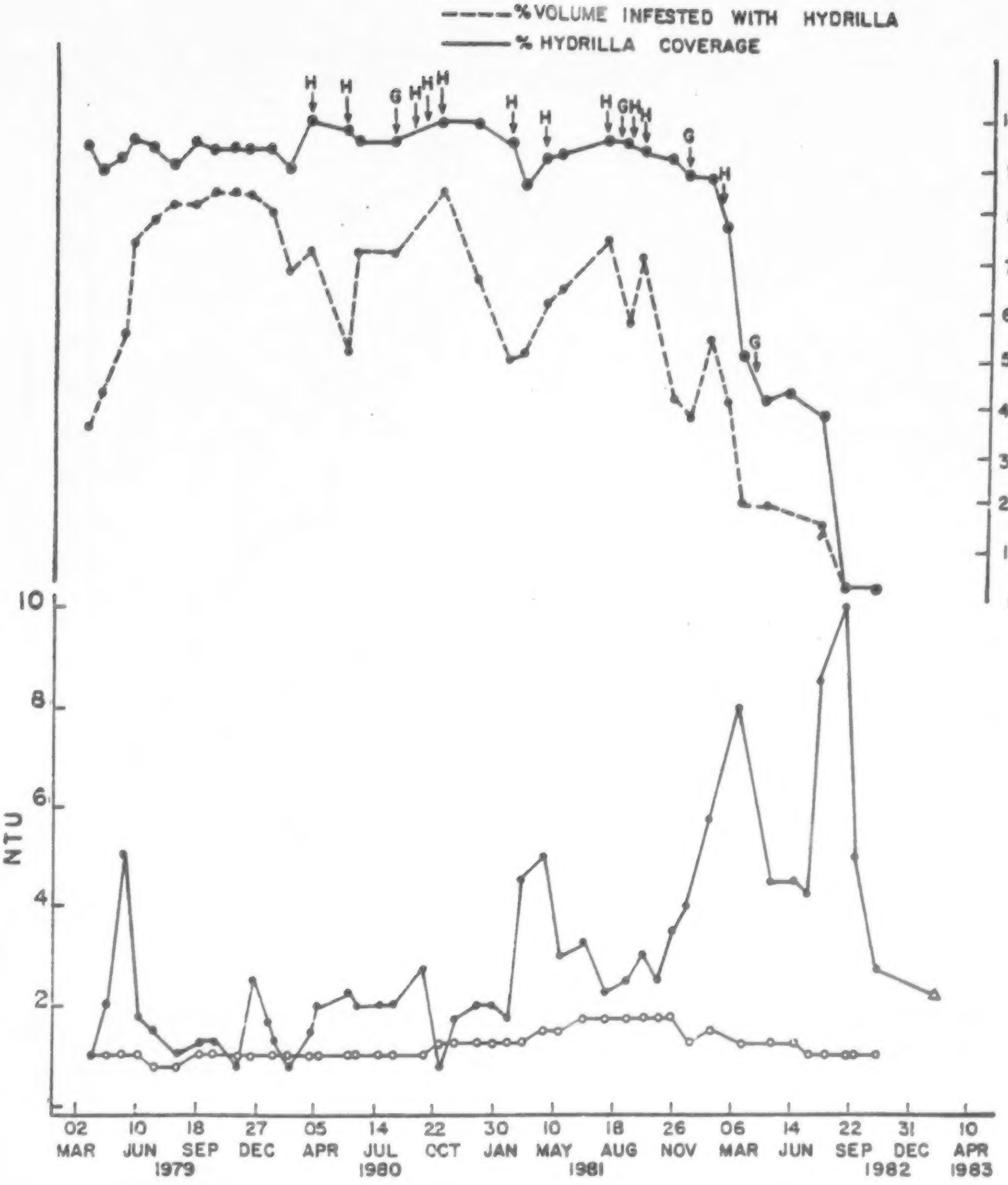

Figure 36. Changes in average turbidity values measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatements and G represents grass carp stocking.

Average monthly pheophytin levels varied from slightly above zero to more than 15 mg/m³ (Figure 37). Multiple regression analysis suggested that changes in lake volume or macrophyte abundance had little effect on pheophytin concentrations ($R^2=0.06$). No consistent effects of the herbicide treatments or grass carp treatments could be demonstrated although the highest pheophytin concentrations coincided with a herbicide treatment.

Average monthly chlorophyll a concentrations ranged from near zero to over 60 mg/m³ (Figure 38). Peak chlorophyll concentrations occurred when major reductions in macrophyte abundance (expressed as a percent of the lake's total volume infested with macrophytes) occurred and low chlorophyll a concentrations occurred when macrophyte abundance was high. Chlorophyll increases occurred whether herbicides, grass carp or natural factors reduced macrophyte abundance. With the total removal of vegetation, a large increase in chlorophyll a concentrations occurred, but the increase was temporary and chlorophyll levels returned to lower levels within a short time.

Orange Lake

Orange Lake is located in the Central Valley physiographic division. This division is a large lowland area extending from Alachua County to northern Orange County (White 1970). In the vicinity of Orange Lake, regional geology is dominated by deposits of the phosphatic Hawthorn Formation. Canfield (1981) found that the major lakes in the northern portion of the Central Valley (Lochloosa Lake, Orange Lake, Newnans Lake, and Lake Wauberg) were all eutrophic, soft-water lakes. Canfield (1981) found that pH values in the lakes ranged from 6.7 to 9.1. Total alkalinity concentrations ranged from 12 to 39 mg/l as $CaCO_3$ and specific conductance ranged from 54 to 84 umhos/cm. Total phosphorus concentrations ranged from 0.01 to 0.11 mg/l and total nitrogen concentrations ranged from 0.88 to 2.8 mg/l. Chlorophyll a concentrations ranged from 24 to

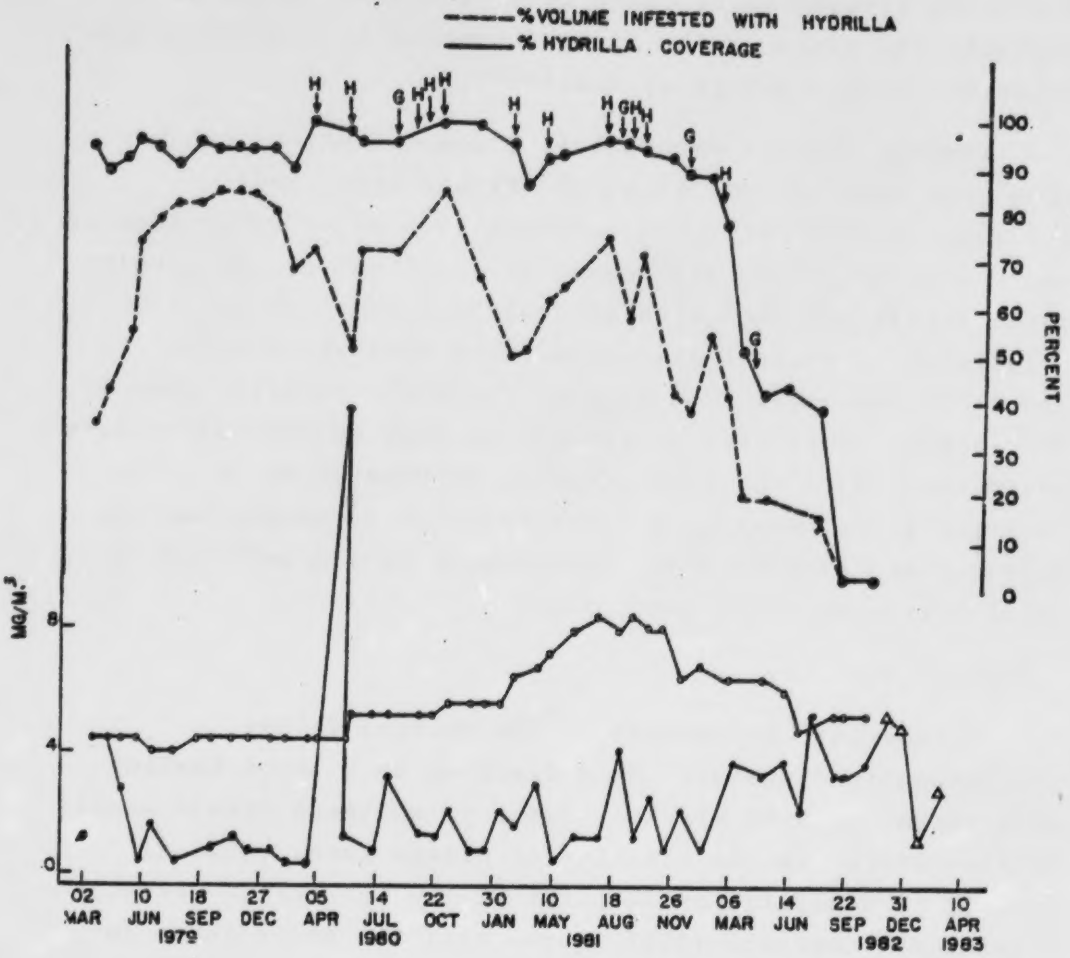

Figure 37. Changes in average pheophytin concentrations measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

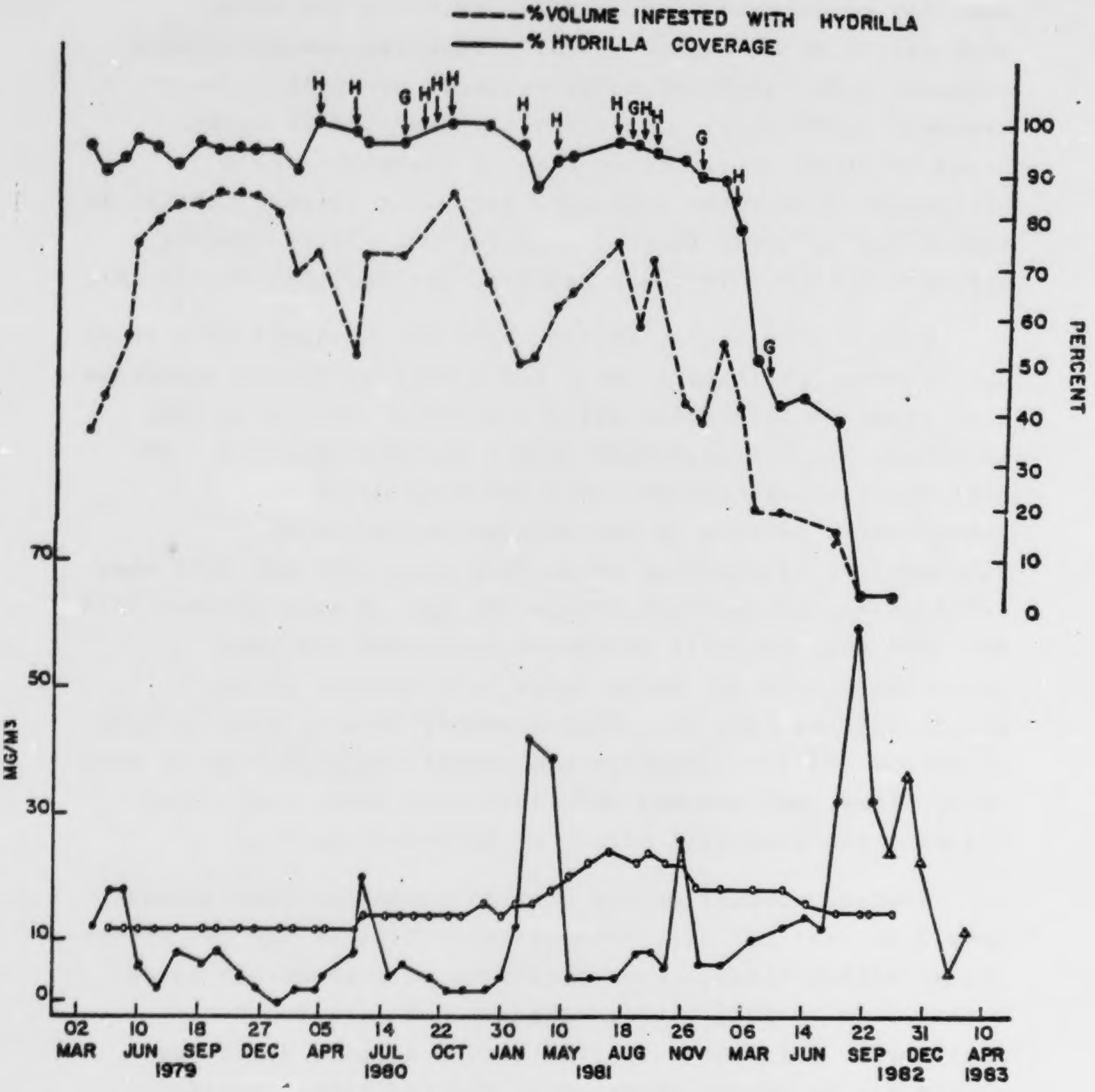

Figure 38. Changes in average chlorophyll a values measured in Lake Pearl. Closed circles are values measured during the study and open circles are predicted values based on changes in lake volume. Open triangles are values measured after this study. H represents herbicide treatments and G represents grass carp stockings.

123 mg/l and color values ranged from 15 to 150 Pt-Co units. During the present study (Table 18), pH in Orange Lake averaged 6.7 and bicarbonate alkalinity averaged 12 mg/l. Specific conductance averaged 70 umhos/cm and color averaged 39 Pt-Co units. Total phosphorus concentrations averaged 0.044 mg/l and total nitrogen concentrations averaged 0.864 mg/l. Chlorophyll a averaged 20 mg/m³. Based on these data, Orange Lake is classified as a eutrophic, soft-water lake that has water quality similar to that found in other lakes in the region. Water quality parameters in Orange Lake, however, are variable (Table 39).

During this study, average monthly pH ranged from about 6.1 to over 7.4 (Figure 39). The lowest pH values coincided with rises in lake level which suggested changes in lake hydrology had a significant effect on lake water pH. No statistically significant relationships could be demonstrated between pH and macrophyte abundance. Furthermore, examination of pH data from 1967 and 1973 when hydrilla was not present (Table 19) and pH data between 1974 and 1979 when hydrilla abundance increased and then decreased (Table 20) shows there have been no major alterations in lake pH. This probably results because lake hydrology and phytoplankton can greatly influence pH in this lake. Also, our samples were from open water areas thus reducing the potential effect of macrophytes.

Average monthly carbon dioxide concentrations ranged from 0 to over 2.7 mg/l (Figure 40). Towards the end of the study, carbon dioxide concentrations were generally lower. During this period, submersed macrophyte abundance had increased. This suggests that carbon dioxide uptake by plants may be partly responsible for the lower levels. Regression analyses, however, indicates 30% of the observed variance can be attributed to changes in lake levels. During the latter part of this study, water levels in Orange Lake dropped considerably (Figure 41). This suggests that carbon dioxide inputs or inputs of carbon dioxide precursors

Table 18. Mean, standard error, and range of water quality parameters measured in Orange Lake between November 1978 and January 1982.

Parameter	Mean	Standard Error	Minimum	Maximum
pH	6.7	0.1	5.9	9.3
Carbon Dioxide (mg/l)	1.1	0.1	0	10
Bicarbonate (mg/l)	12	0.1	1.8	28
Carbonate (mg/l)	0.2	0.1	0	7.2
Specific Conductance (mhos/cm at 25° C)	70	0.3	54	87
Calcium (mg/l)	6.4	0.1	4.0	15
Magnesium (mg/l)	2.2	0.02	1.2	6.1
Potassium (mg/l)	0.4	0.02	0	2.9
Orthophosphate (mg P/l)	0.012	0.001	0	0.214
Total Phosphorus (mg P/l)	0.044	0.002	.002	0.258
Total Nitrogen (mg N/l)	0.864	0.017	0.360	2.36
Turbidity (NTU)	4	0.3	0.4	55
Chlorophyll *a* (mg/m)	20	0.8	0.7	47
Pheophytin (mg/m)	3.8	0.3	0	29
Color (Pt-Co units)	39	2	10	175

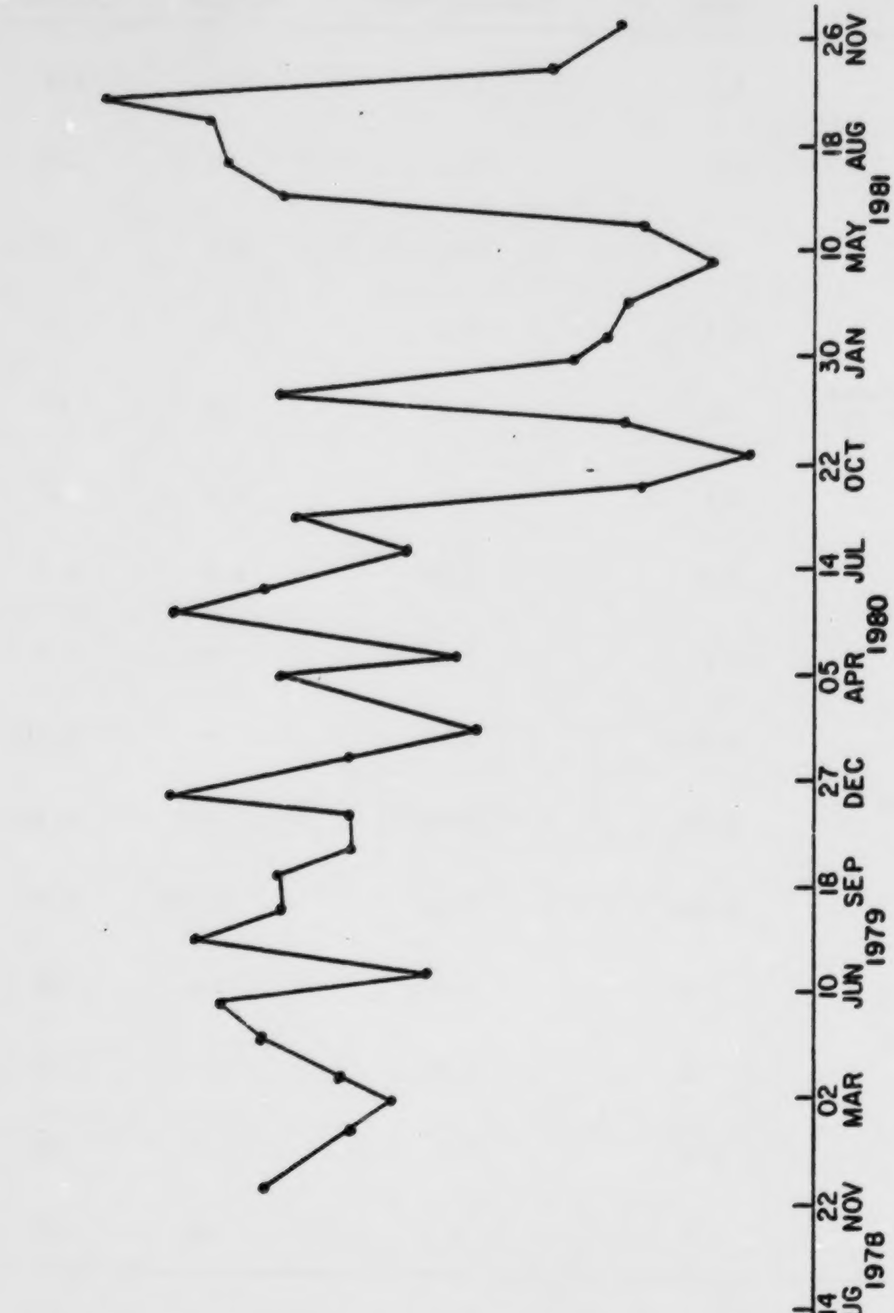

Figure 39. Average monthly pH values for Orange Lake, 1978-1981.

Table 19. Average and range of chemical values measured in Orange Lake between 1967 and 1973. Data taken from Canfield (1981).

Parameter	Mean	Minimum	Maximum
pH	7.6	7.0	8.8
Total Alkalinity (mg/l as $CaCO_3$)	17	14	21
Specific Conductance (μmhos/cm)	89	76	100
Calcium (mg/l)	6.1	5.2	7.2
Magnesium (mg/l)	1.8	1.6	1.9
Potassium (mg/l)	0.6	0.4	0.9
Total Phosphorus (mg/l)	0.04	0.03	0.06
Chlorophyll *a* (mg/m^3)	19	6.4	35

Table 20. Chemical values measured in Orange Lake between October 1974 and August 1979. Data from United States Geological Survey Station 02242450 at Orange Lake, Florida.

Date	pH	Conductivity (μmhos/cm)	Bicarbonate (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Total Phosphorus (mg/l)	Total Nitrogen (mg/l)	Turbidity (NTU)	Color (Pt-Co units)
10/10/74	7.9	73	-	-	-	-	.02	.81	4	-
4/4/75	-	76	21	5.9	1.9	-	.02	.86	3	-
8/25/75	6.0	70	-	-	-	.2	.02	.97	7	-
11/17/75	4.9	82	31	7.3	1.9	.1	.02	.83	3	75
4/27/76	7.5	91	-	-	-	-	.01	.82	3	-
8/6/76	7.5	86	-	-	-	-	.03	.84	2	-
10/13/76	7.2	87	31	7.6	2.2	.1	.03	.78	2	10
6/1/76	7.1	102	32	9.0	3.0	.2	.03	1.0	3	10
11/3/77	7.2	118	42	10.0	3.2	.1	.02	1.2	5	23
5/25/78	7.0	117	36	11.0	2.9	1.0	.13	2.5	8	70
9/7/78	7.3	107	-	-	-	-	.08	1.4	4	-
11/29/76	7.4	97	29	8.1	2.5	1.2	.07	1.4	-	70
6/6/79	6.8	90	31	7.8	2.1	.6	.05	1.1	-	40
8/20/79	7.2	-	-	-	-	-	.04	.88	-	-

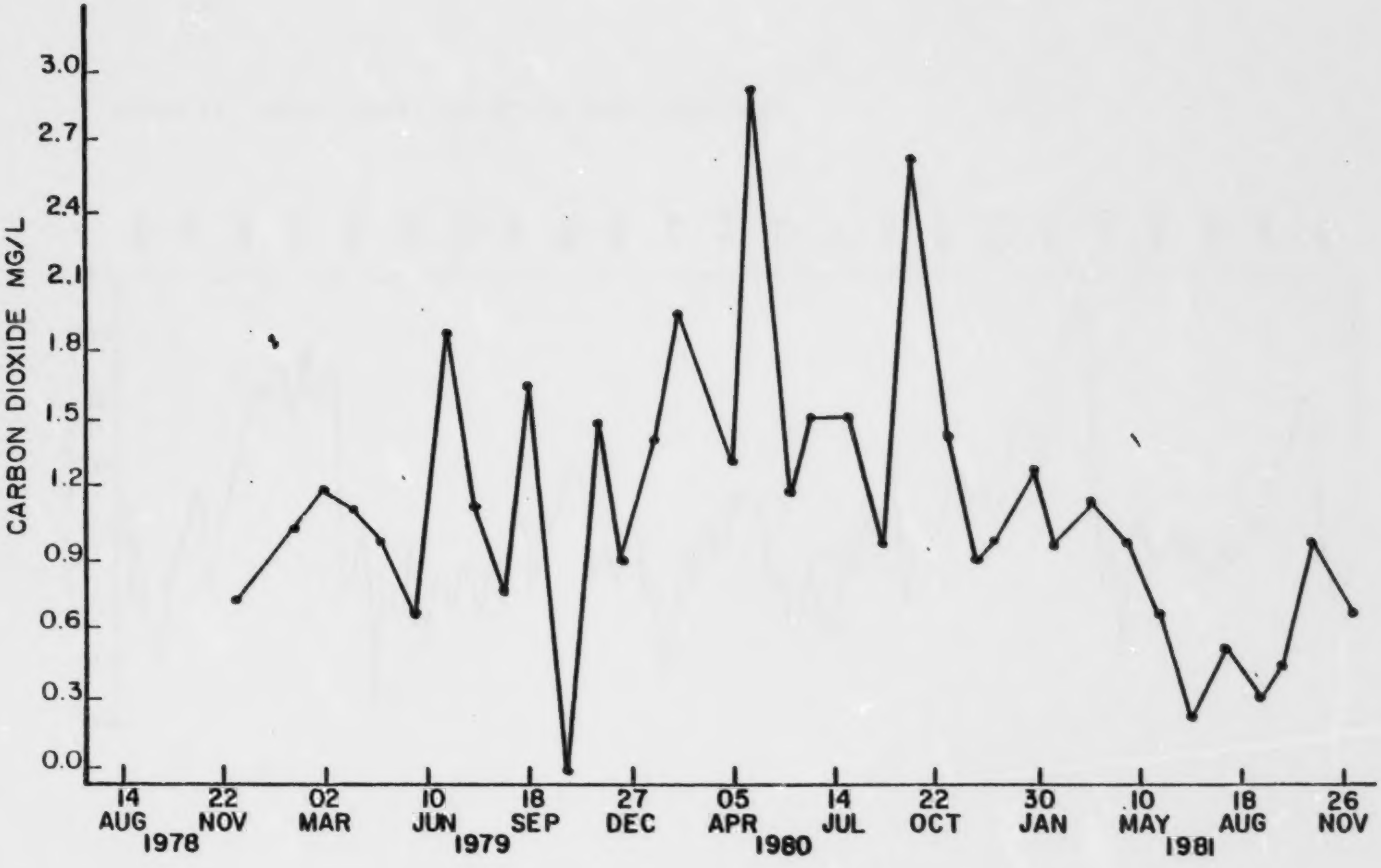

Figure 40. Average monthly carbon dioxide values for Orange Lake, 1978-1981.

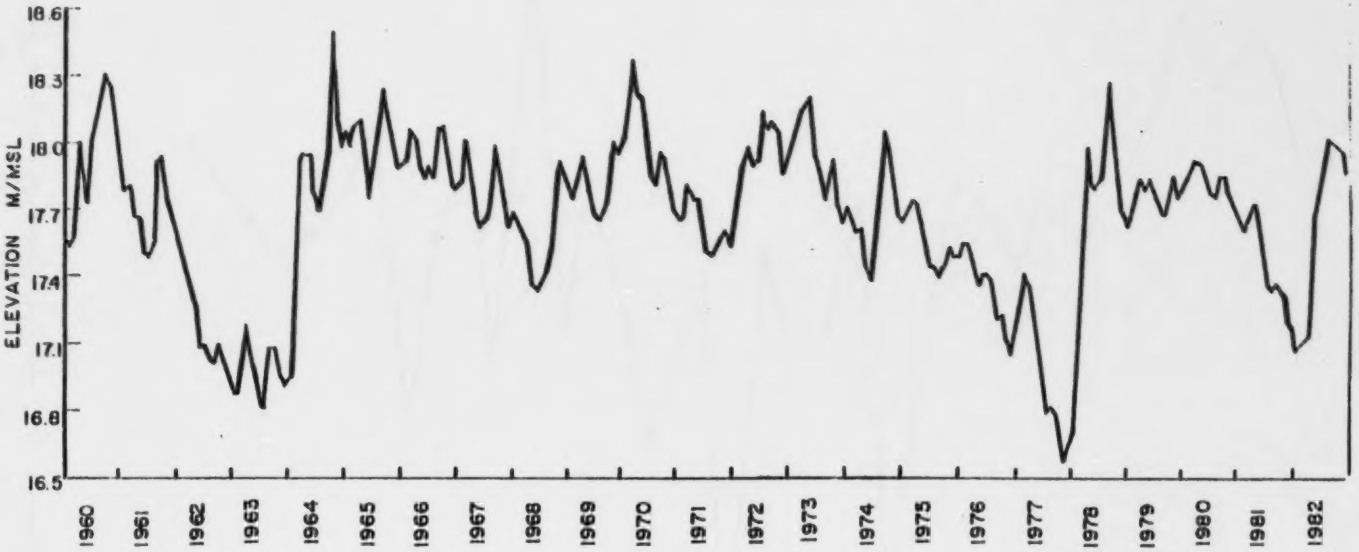

Figure 41. Water levels for Orange Lake, 1960-1982.

from the watershed were lower and consequently lower concentrations would occur in the lake.

Mean monthly bicarbonate concentrations ranged from less than 10 to over 13 mg/l (Figure 42). Bicarbonate concentrations were generally lower between April 1980 and August 1981, which coincides with large increases in hydrilla abundance, but no statistically significant relationships between bicarbonate concentrations and hydrilla abundance could be demonstrated. Furthermore, total alkalinity measurements made prior to the introduction of hydrilla (Table 19) indicates that hydrilla has not drastically altered alkalinity levels in Orange Lake.

Average monthly carbonate concentrations ranged from zero to over 1.4 mg/l (Figure 43). There was no relationship between carbonate concentrations and submersed macrophyte abundance. Carbonate concentrations, however, were generally high when chlorophyll a concentrations (Figure 44) were high. This suggests that photosynthetic activity by plankton algae is primarily responsible for the major changes in carbonate concentrations although some impact by aquatic macrophytes can not be ruled out.

Average monthly specific conductance ranged from 56 umhos/cm to approximately 80 umhos/cm (Figure 45). No relationships between specific conductance and macrophyte abundance were demonstrated. Overall, there was a general trend for increased conductivity as the study progressed. This coincided with reduced water levels (Figure 41). Data collected during 1977 and 1978, years with low water (Table 20) demonstrated that specific conductance increases in Orange Lake when water levels decrease. This supports the hypothesis that hydrologic factors are primarily responsible for changes in specific conductance.

Monthly calcium concentrations ranged from less than 5.3 mg/l to about 9.0 mg/l (Figure 46) and average monthly magnesium concentrations ranged from less than 1.7 mg/l to

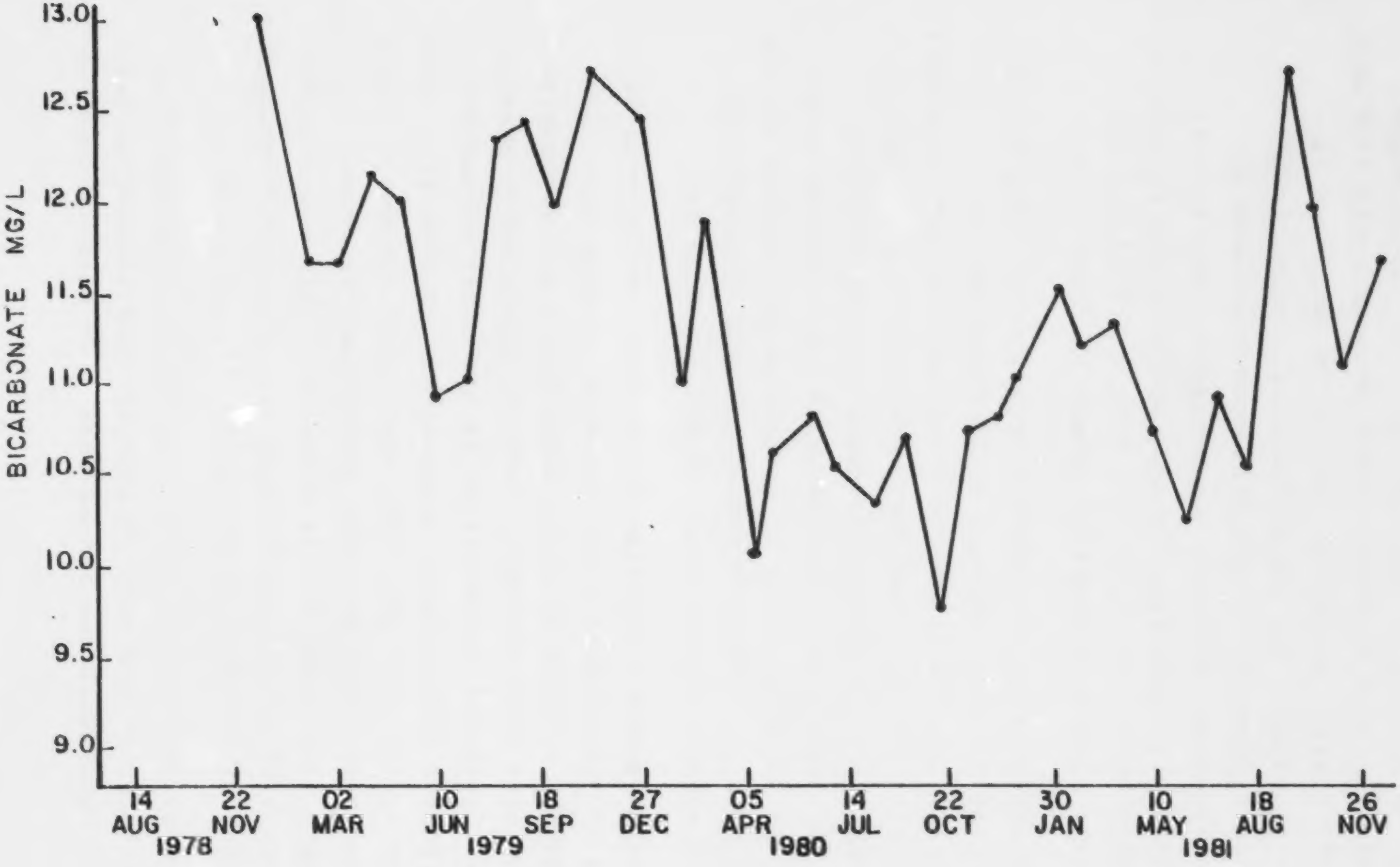

Figure 42. Average monthly bicarbonate values for Orange Lake, 1978-1981.

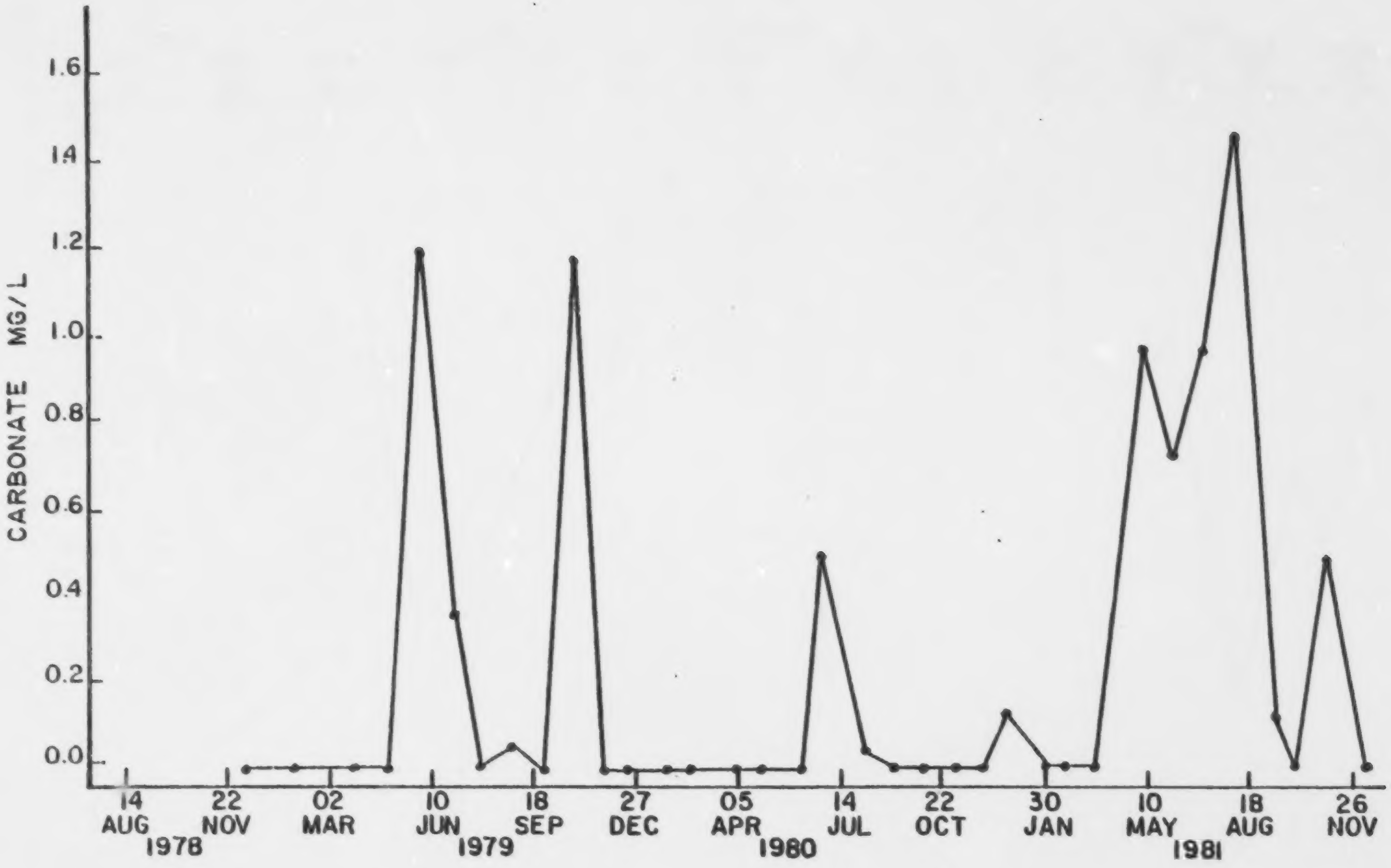

Figure 43. Average monthly carbonate values for Orange Lake, 1978-1981.

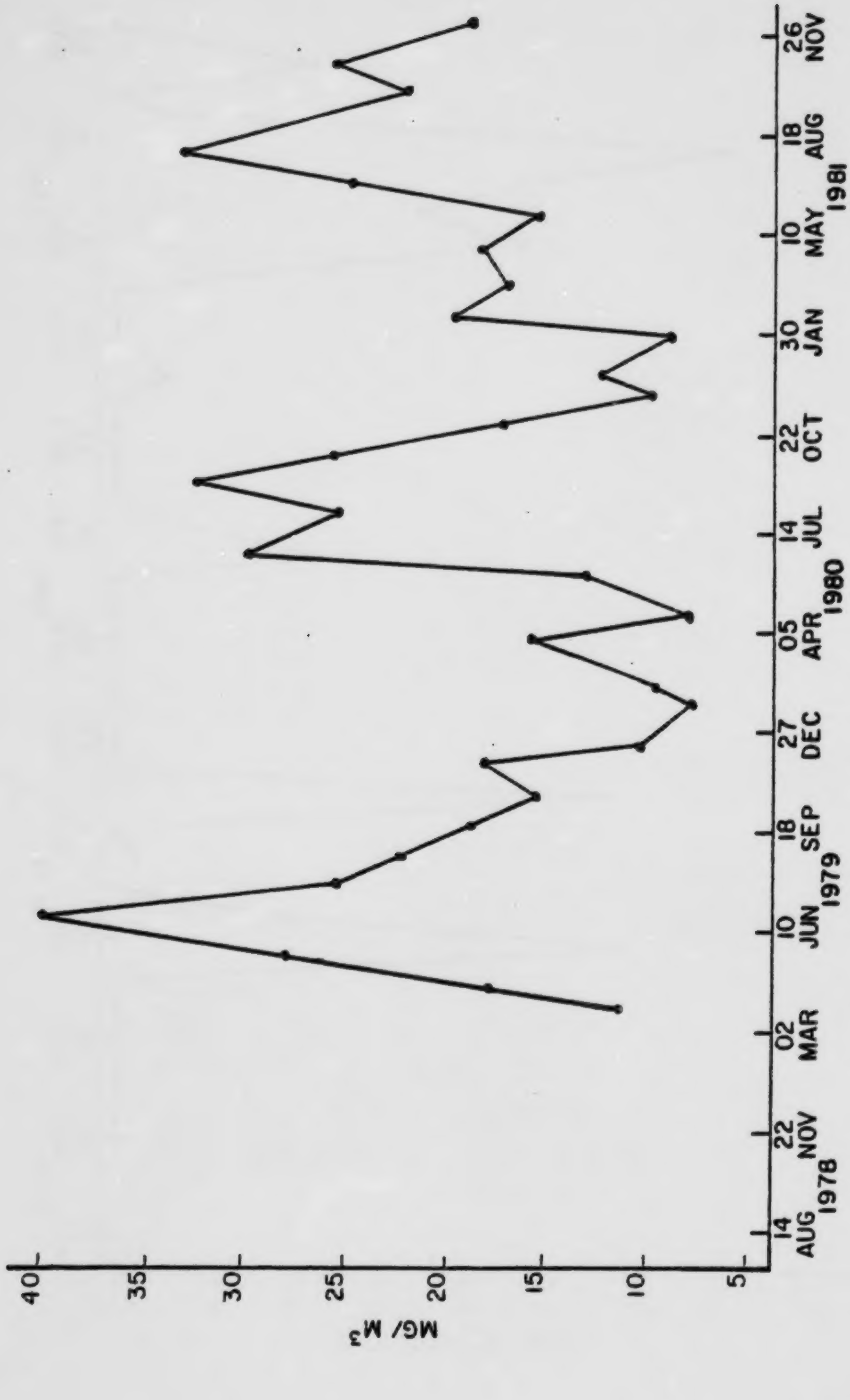

Figure 44. Average monthly chlorophyll a values for Orange Lake 1978-1981.

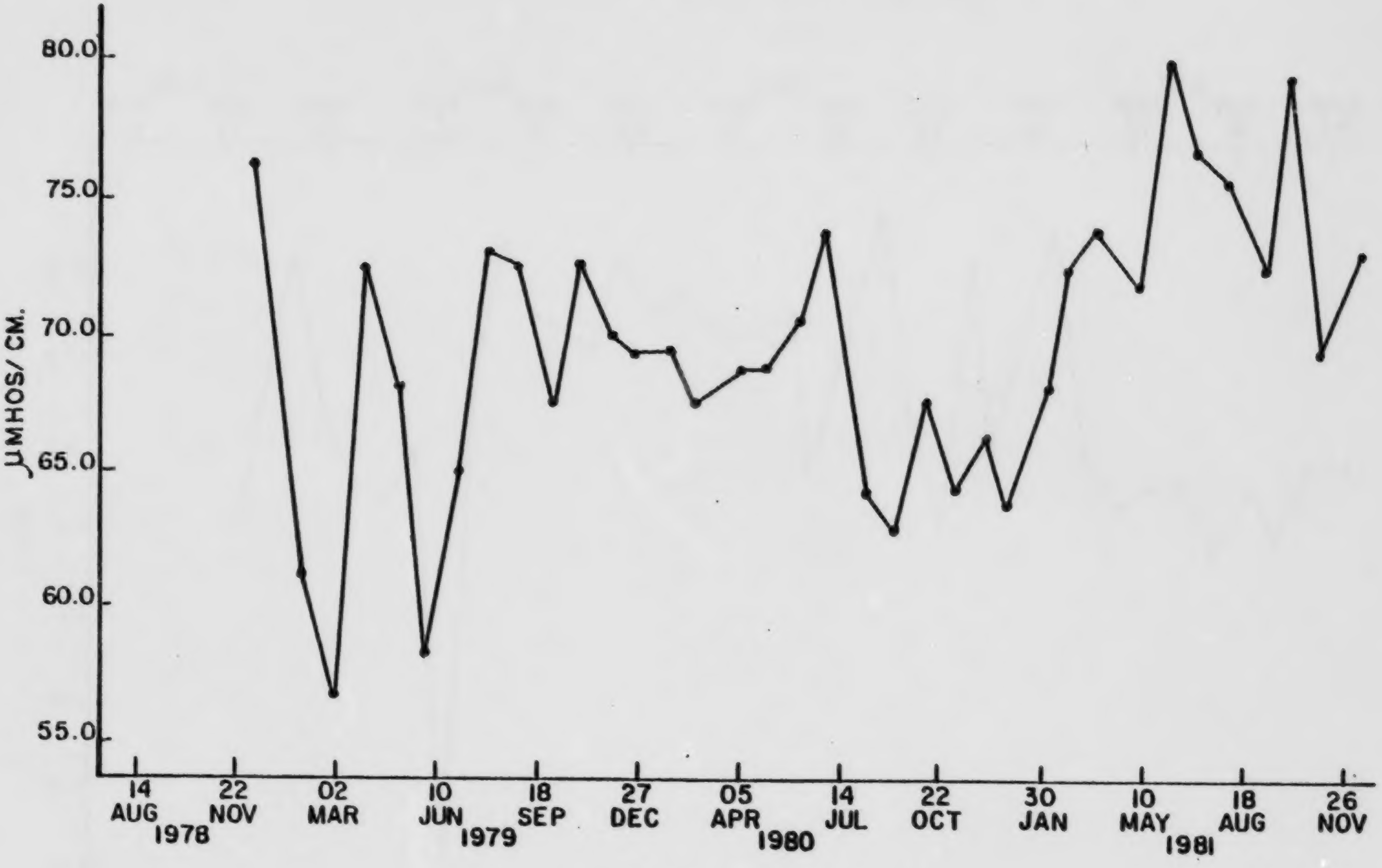

Figure 45. Average monthly conductivity values for Orange Lake, 1978-1981.

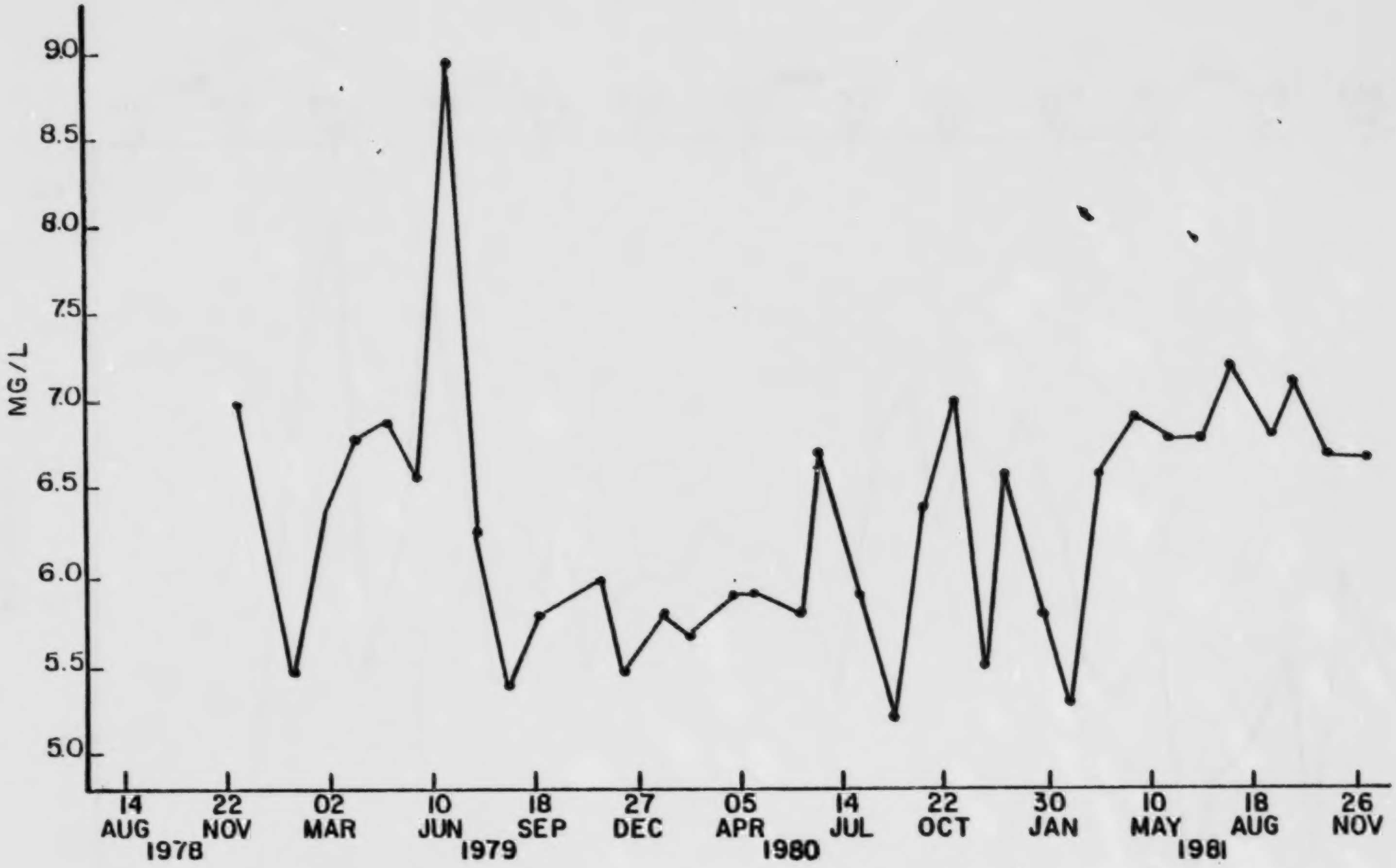

Figure 46. Average monthly calcium values for Orange Lake, 1978-1981.

over 2.9 mg/l (Figure 47). No significant trends in calcium and magnesium concentrations could be shown with changes in macrophyte abundance, especially hydrilla abundance. For both calcium and magnesium, there was a general trend of slightly higher concentrations at the beginning and end of the study. During the middle portion of this study, water levels were generally higher (Figure 41). This suggests that changes in lake hydrology were primarily responsible for changes in calcium and magnesium concentrations. Further support for this hypothesis comes from data collected during 1977-1978 when water levels were much lower (Figure 41). During this period (Table 20), measured calcium concentrations were between 9 and 11 mg/l and measured magnesium concentrations were between 2.9 and 3.2 mg/l. These values are higher than those measured in this study or those measured between 1967 and 1973 (Table 19) when water levels were higher.

Average monthly total nitrogen concentrations ranged from about 2.0 mg/l to less than 0.6 mg/l (Figure 49). Total phosphorus concentrations ranged from less than 0.02 mg/l to over 0.15 mg/l (Figure 48) and orthophosphate concentrations ranged from 0 to 0.08 mg/l (Figure 50). Average monthly potassium concentrations ranged from less than 0.1 to 1.0 mg/l (Figure 51). For all these nutrients, the highest concentrations occurred prior to June 1979 and significant declines occurred from peak values. Data from 1977 and 1978 (Table 20) showed that the high concentrations coincided with a rapid rise in water level (Figure 41). The effects of macrophytes on these parameters is not clear. The loss of large amounts of hydrilla following the rise in water in 1978 may have contributed large amounts of nutrients to the overlying water. Inputs of nutrients from the watershed also probably caused a rise in nutrient levels. However, the flooding of large areas of exposed lake bottom containing oxidized sediments and decomposing plant material probably contributed large amounts of nutrients to the lake. This being similar to what occurs

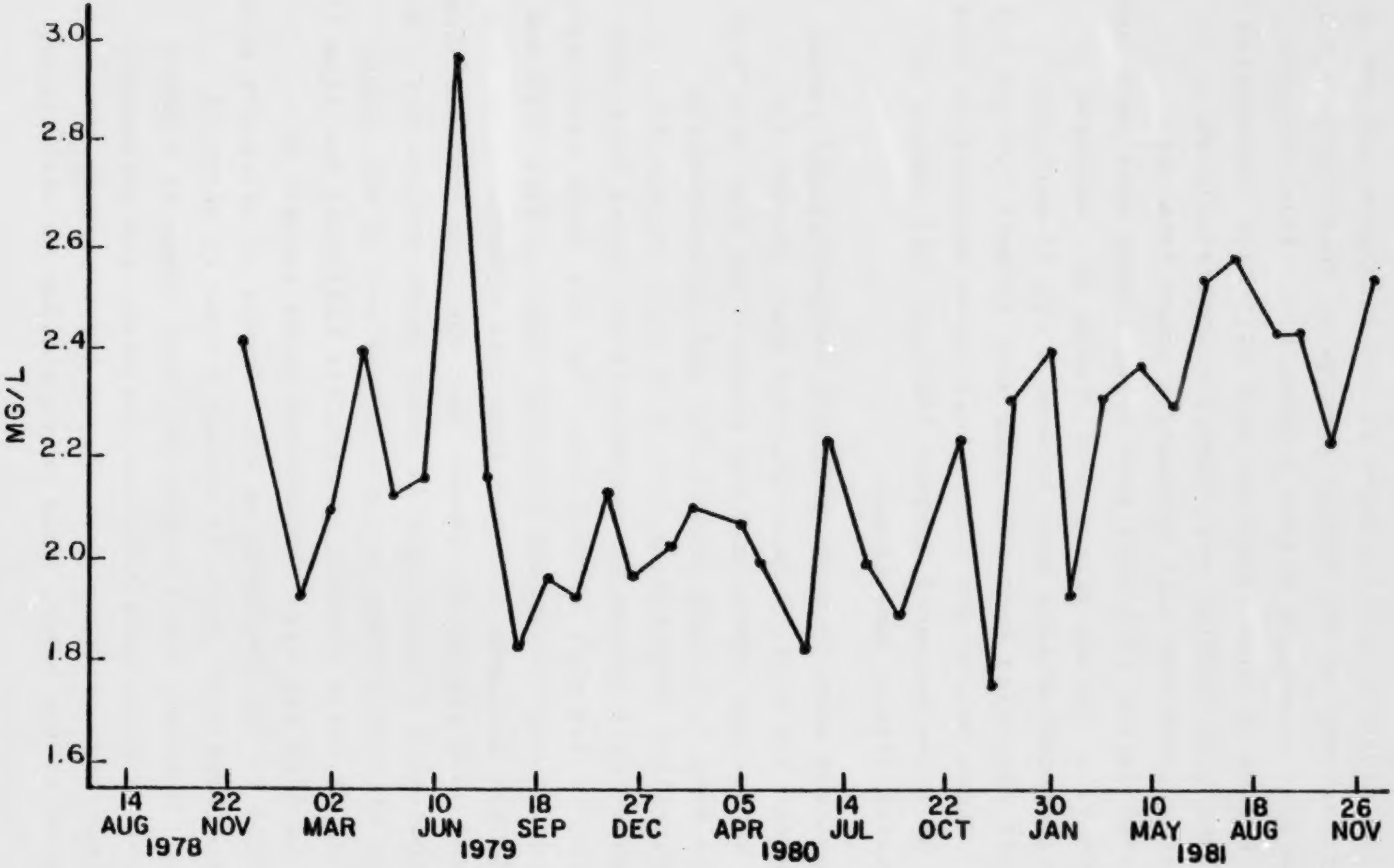

Figure 47. Average monthly magnesium values for Orange Lake, 1978-1981.

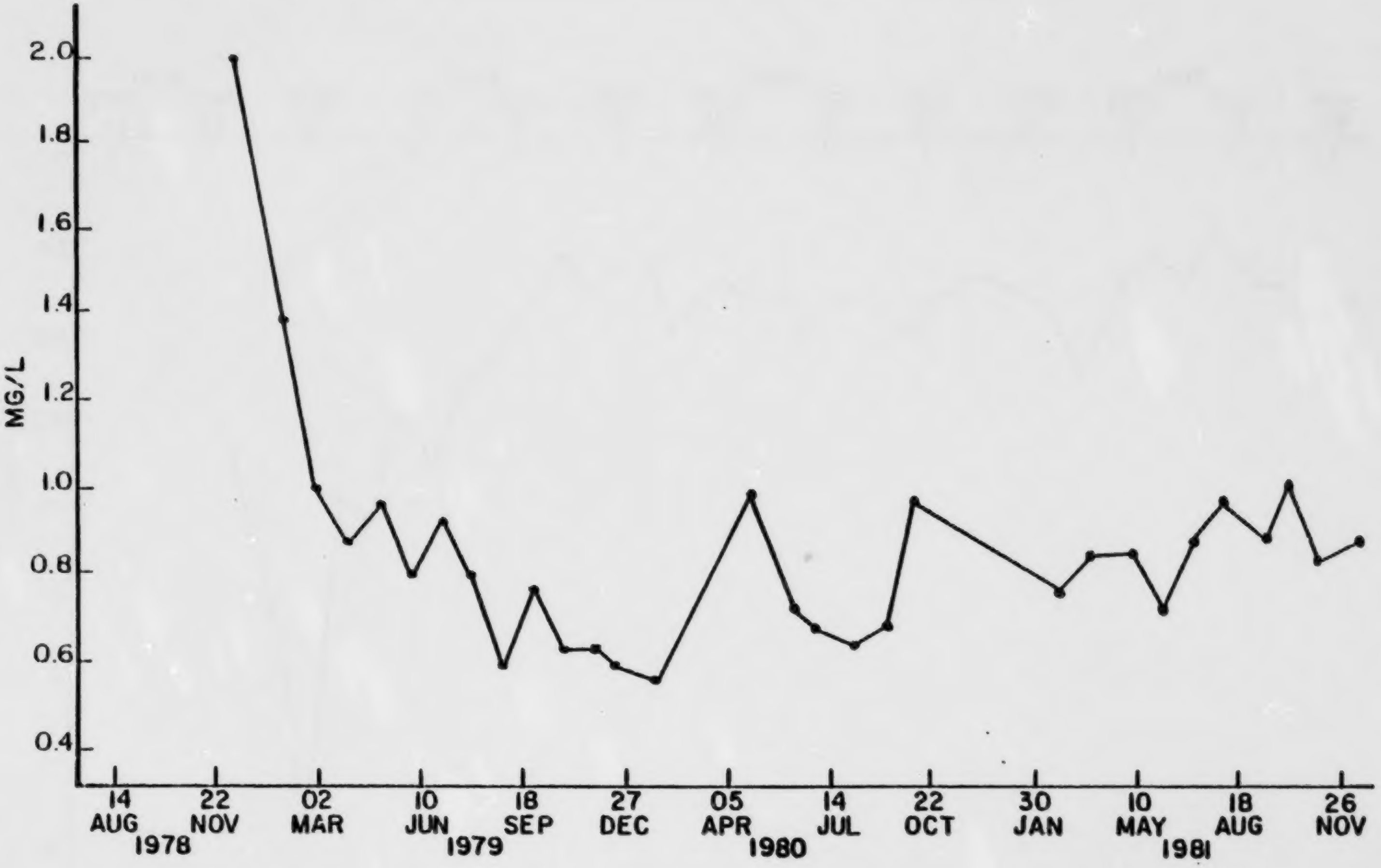

Figure 48. Average monthly nitrogen values for Orange Lake, 1978-1981.

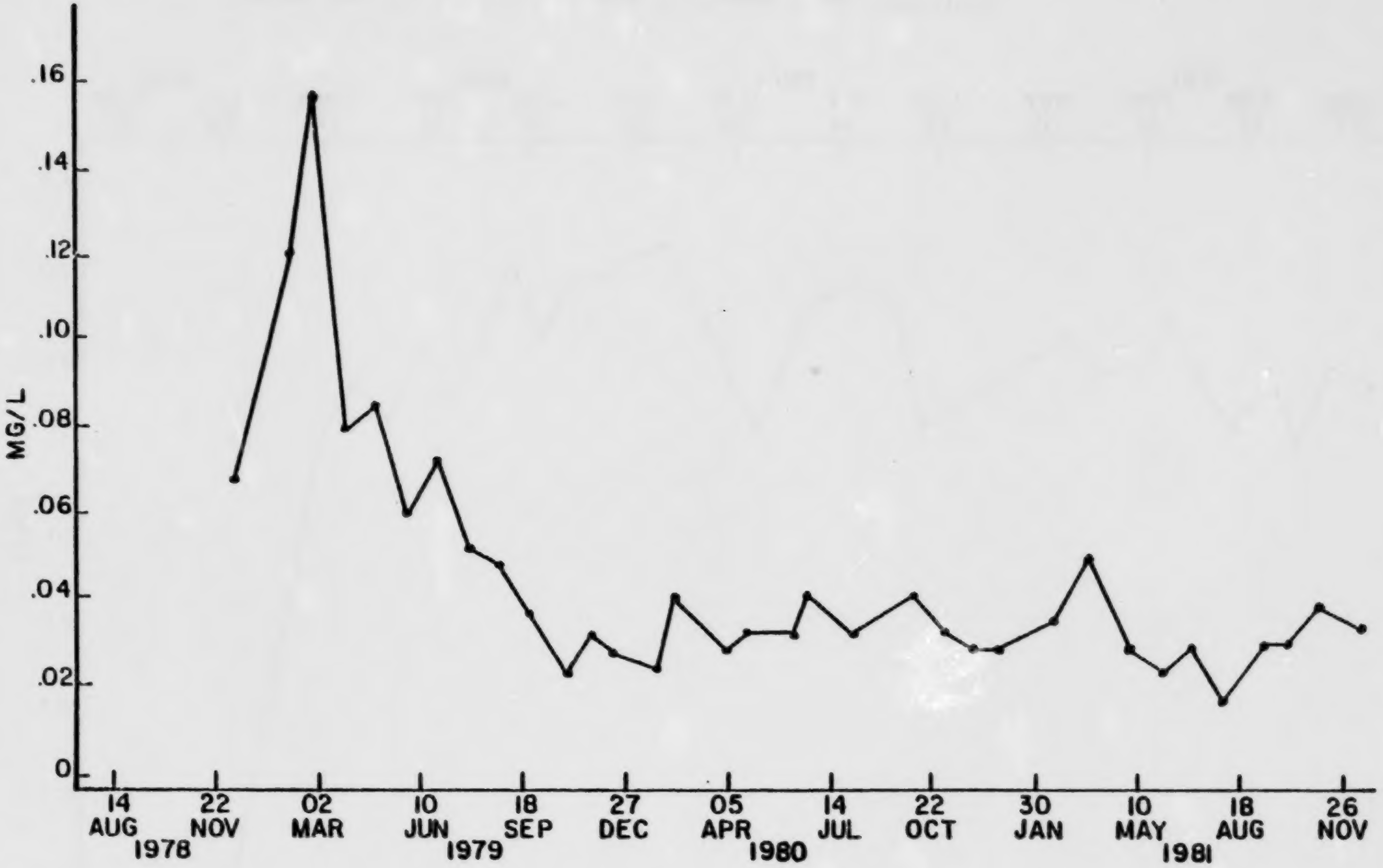

Figure 49. Average monthly total phosphate values for Orange Lake, 1978-1981.

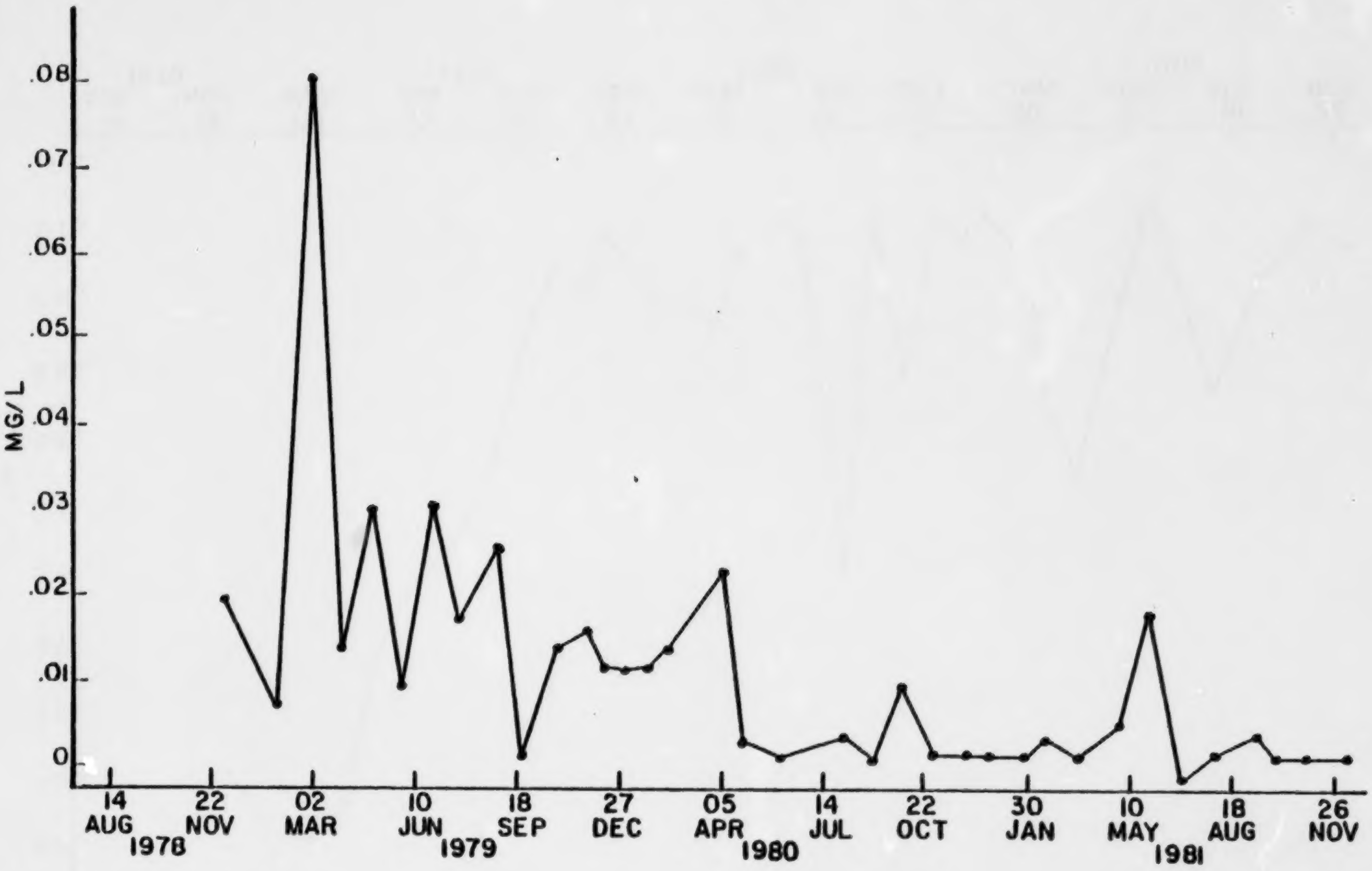

Figure 50. Average monthly orthophosphate values for Orange Lake, 1978-1981.

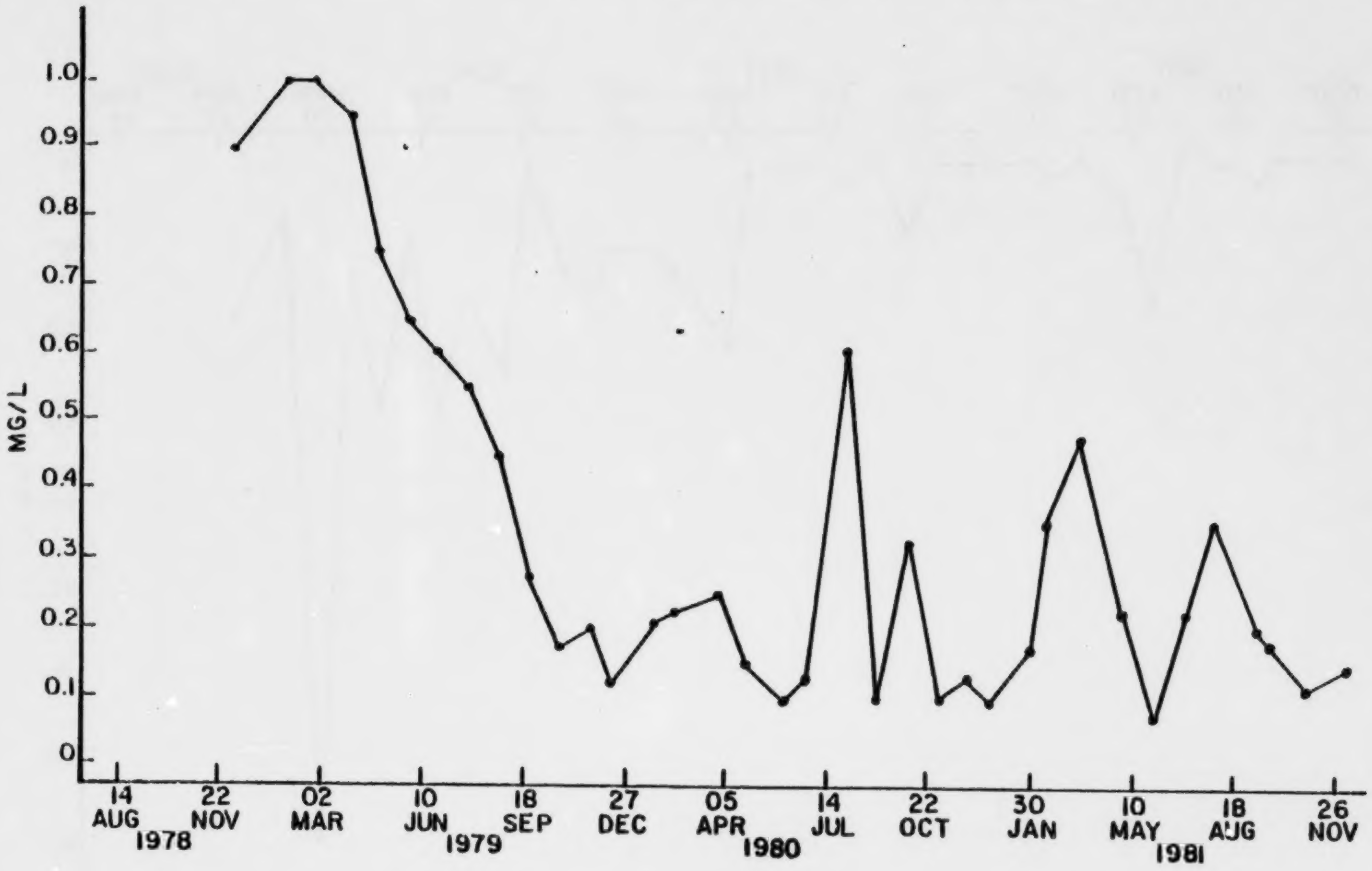

Figure 51. Average monthly potassium values for Orange Lake, 1978-1981.

when reservoirs are first filled. Nutrient pulses throughout the study generally occurred in association with rises in water level. This suggests that lake hydrology is the dominant factor controlling nutrient concentrations in Orange Lake, not macrophyte abundance. Further support for this hypothesis, comes from water quality data collected during 1967-1973, a period when hydrilla was not present. Average total phosphorus and potassium concentrations for 1967-1973 are not substantially different from concentrations measured during this study (Table 19).

Average monthly color concentrations declined from approximately 90 Pt-Co units to less than 20 Pt-Co units (Figure 52). During the period of decline, water levels were falling. Regression analysis demonstrated that 56% of the sample variance was attributed to changes in water level. Data (Table 20) shows that low color values occurred during the 1976-1977 drought and higher values occurred when water levels increased. High color levels result from inputs of highly colored water from the watershed, therefore, water color in Orange Lake will depend largely on lake hydrology.

Average monthly turbidity values ranged from less than 2 to over 12 NTU (Figure 53). Pheophytin concentrations ranged from 0 to 13 mg/m^3 (Figure 54) and chlorophyll a concentrations ranged from less than 10 mg/m^3 to over 35 mg/m^3 (Figure 44). Significant statistical relationships between macrophyte abundance and these parameters could not be demonstrated nor could any relationship with changes in lake level be shown. Chlorophyll levels, however showed seasonal trends. Peak chlorophyll concentrations generally occurred during the summer and lowest concentrations generally occurred during the winter. Significant chlorophyll declines generally occurred after mid-summer. During this period, hydrilla abundance increased to its late fall maximum. Although statistically significant relationships between macrophytes and chlorophyll a

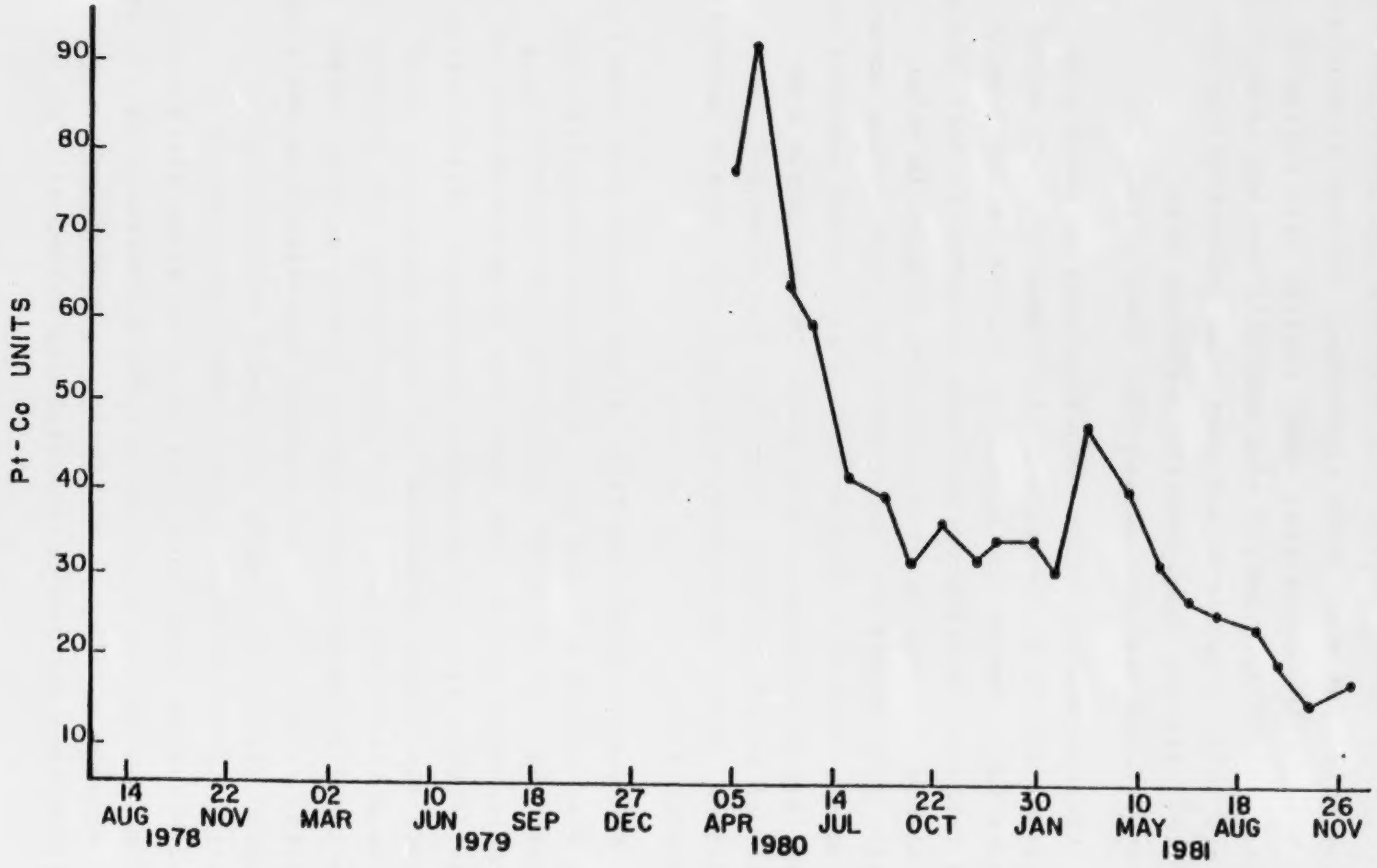

Figure 52. Average monthly color values for Orange Lake, 1980-1981.

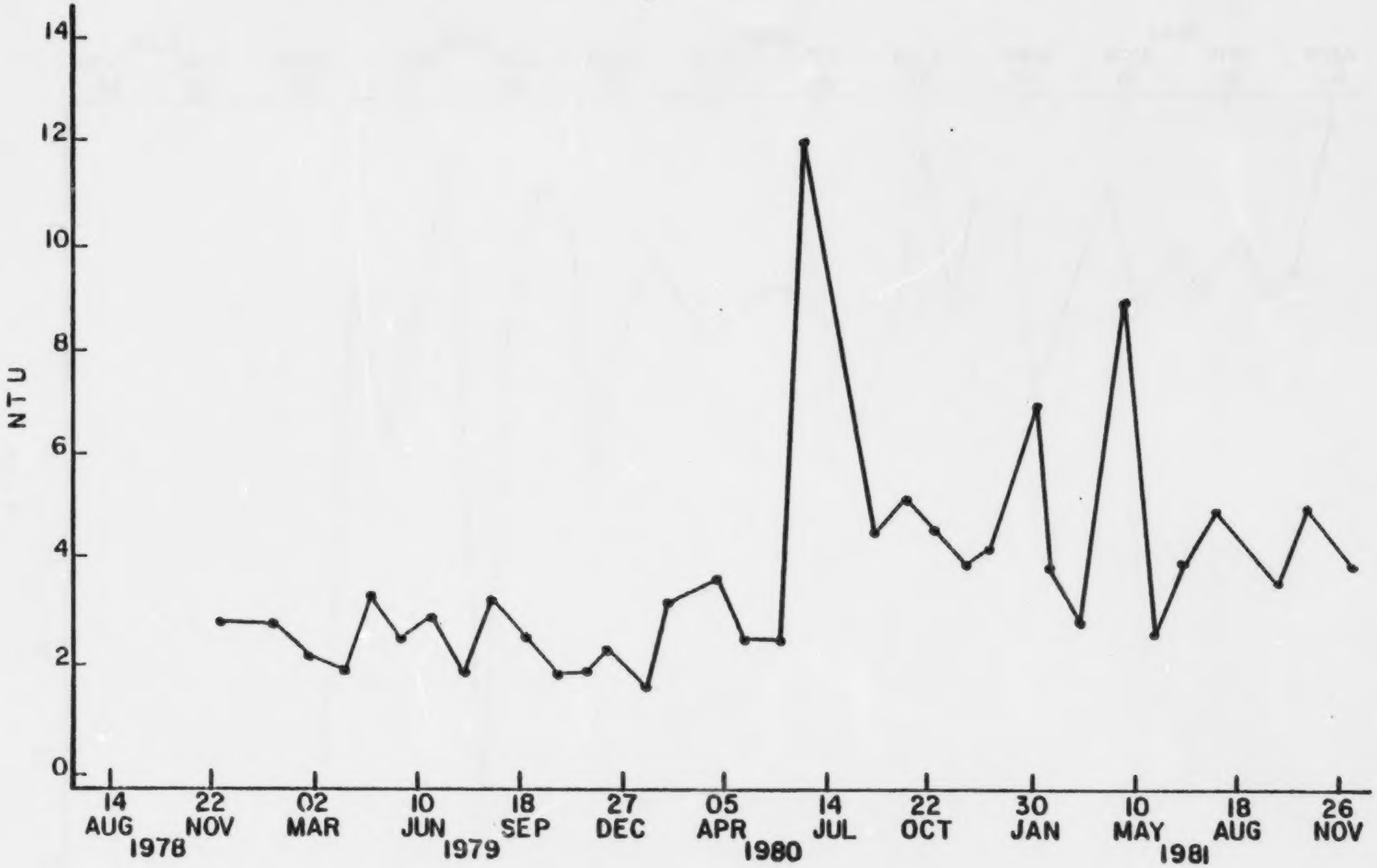

Figure 53. Average monthly turbidity units for Orange Lake, 1978-1981.

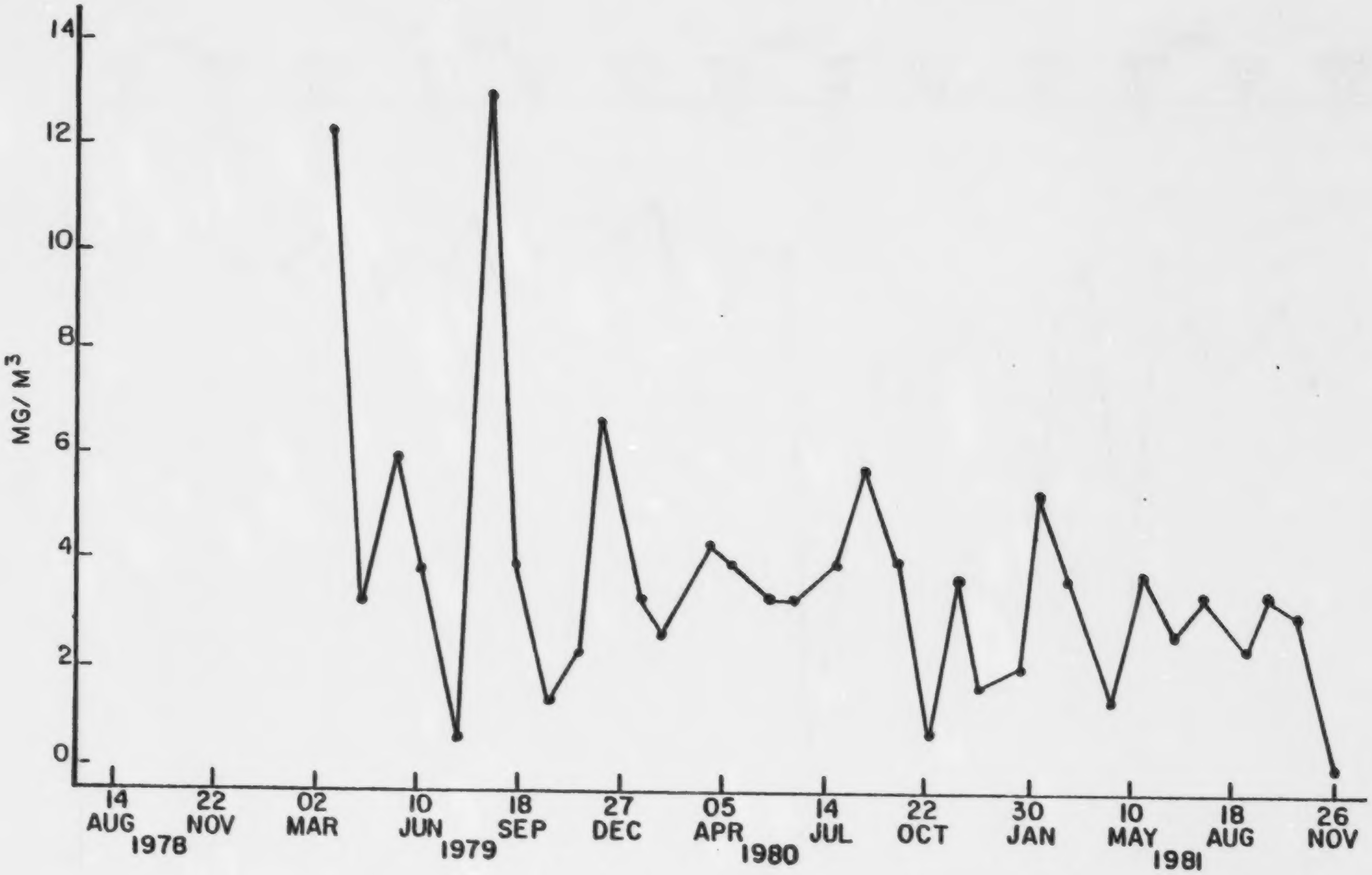

Figure 54. Average monthly pheophytin values for Orange Lake, 1978-1981.

concentrations could not be demonstrated using all the data, there seems to be an inverse relationship between macrophyte abundance and chlorophyll a concentrations during the late summer and fall.

Welaka Ponds

To assess the effects of the different tested aquatic macrophyte management strategies on pond water quality, data from individual ponds were pooled with respect to treatment. Duncan's multiple range test was used to test for treatment differences. Statistical analyses were performed separately for each year and for all data combined. To discern general patterns of response, monthly treatment means were graphed. Aquatic macrophyte abundance was at or near control levels in 1982; therefore, 1982 data should be indicative of potential water quality changes related to different treatments.

Hydrogen ion (Figure 55), carbon dioxide (Figure 56), bicarbonate (Figure 57) and carbonate (Figure 58) concentrations varied considerably during this study. No significant treatment differences, however, were found for pH, bicarbonate and carbonate concentrations (Table 21). In 1982, carbon dioxide concentrations in the control ponds (0% macrophyte control) were significantly higher than those measured in the 100% macrophyte control ponds (Table 21). Although significant, the difference in carbon dioxide concentrations do not represent a major water quality change. Based on these data, the management of macrophytic vegetation seems to have little overall effect on pH, bicarbonate, carbonate, and carbon dioxide levels on a yearly basis. Furthermore, there was a general decline in pH during the study (Figure 55). Because the reductions in pH occurred for all treatments, some common factor such as changes in hydrology might be more responsible for many of the observed changes.

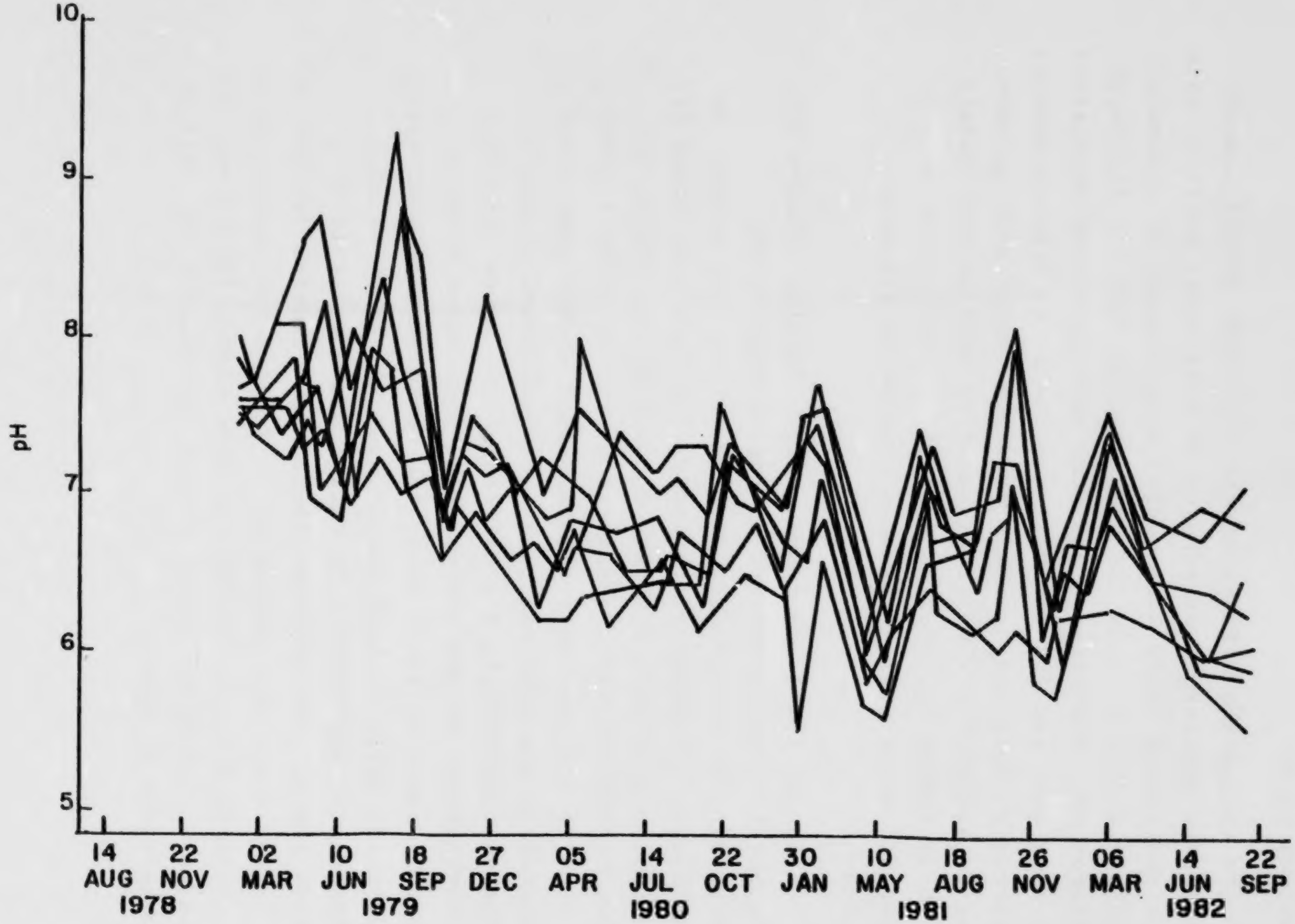

Figure 55. Average monthly hydrogen ion concentrationf for all Welaka study ponds, 1978-1982.

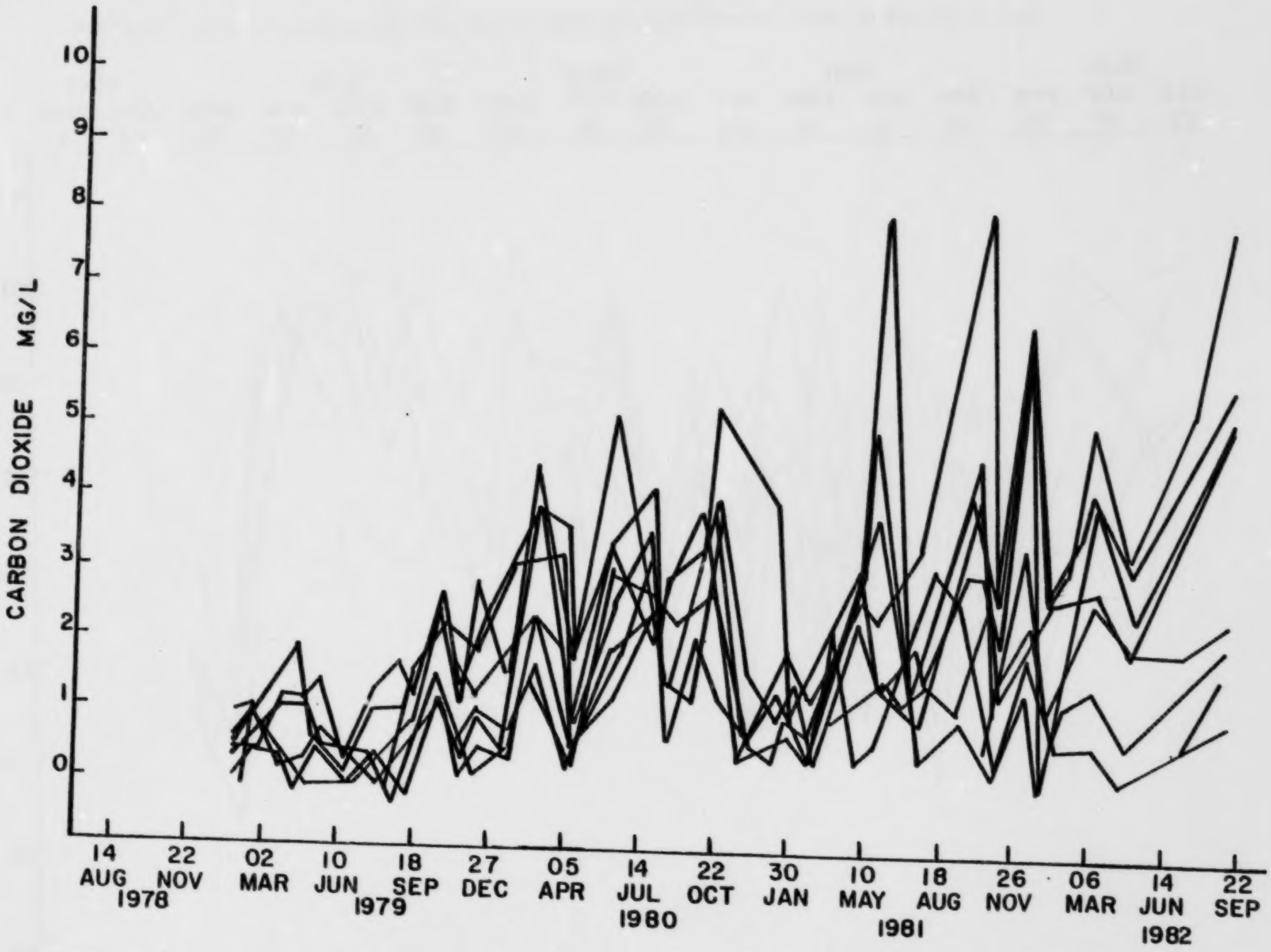

Figure 56. Average monthly carbon dioxide values for all Welaka study ponds, 1978-1982.

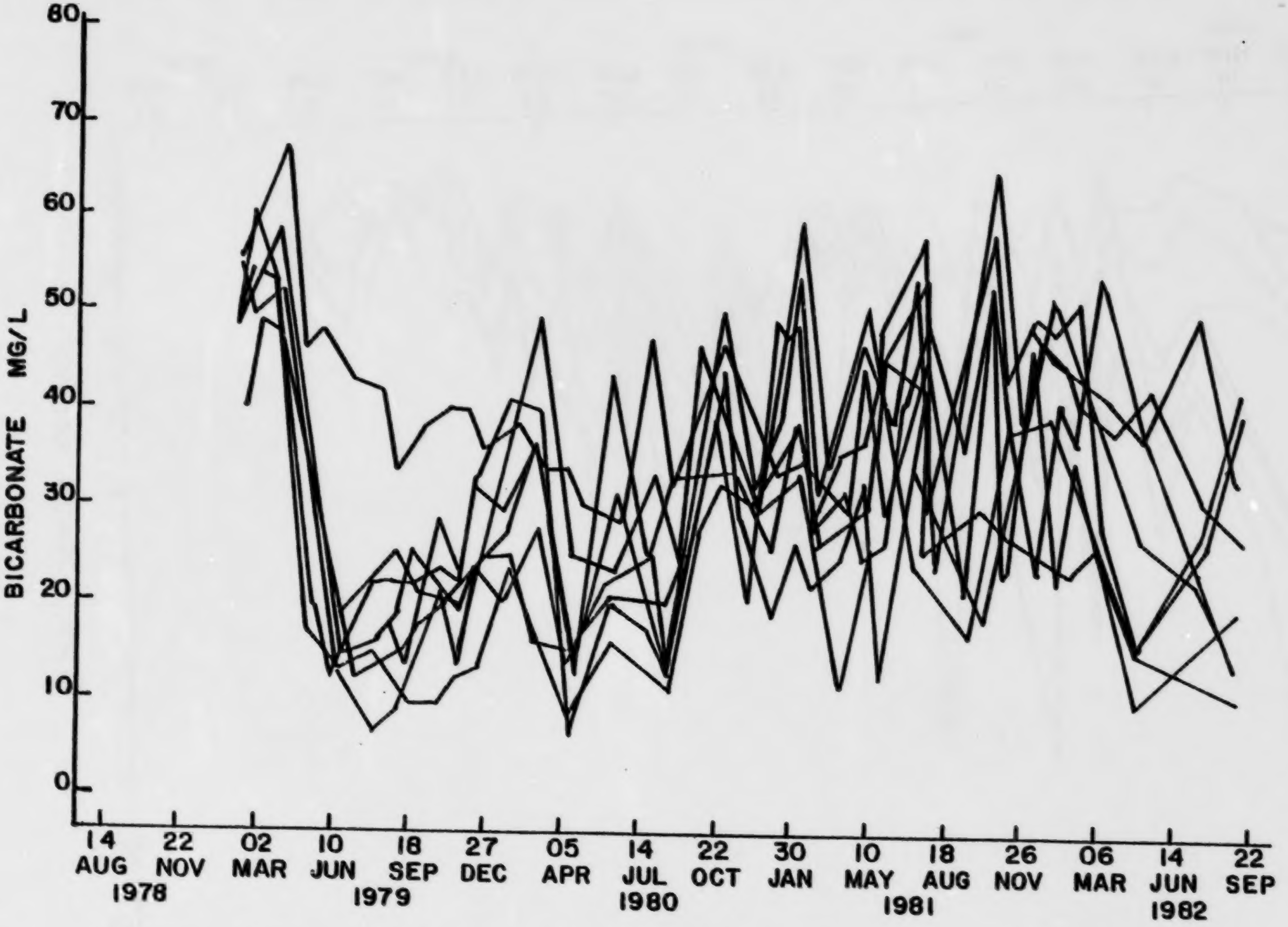

Figure 57. Average monthly bicarbonate values for all Welaka study ponds 1978–1982.

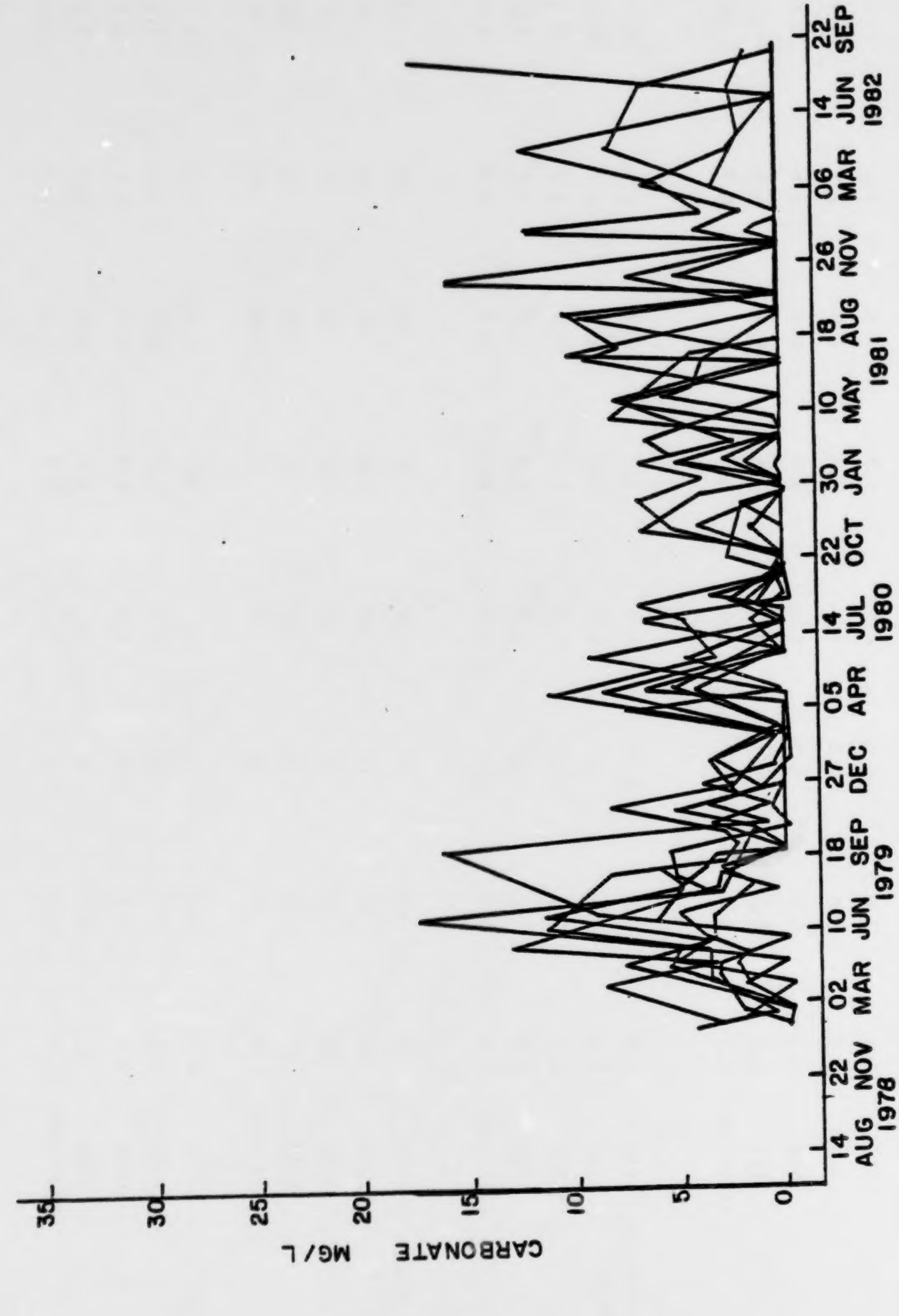

Figure 58. Average monthly carbonate values for all Welaka study ponds, 1978-1982.

Table 21. Treatment means for water quality parameters measured in the Welaka Ponds. Where statistically significant differences (P<0.05) occurred values are marked by letters. Means with the same letter are not significantly different.

			40% Control		70% Control		100% Control		
Parameter	Year	0% Control	Herbicides	Grass Carp	Herbicides	Grass Carp	Herbicides	Grass Carp	Fertilization
pH	1979	6.9	7.0	6.6	6.8	6.7	7.3	7.0	7.5
	1980	6.9	6.6	7.2	6.6	7.4	6.9	7.1	6.8
	1981	6.4	6.1	6.6	6.2	6.8	6.5	6.6	6.8
	1982	6.3	6.5	6.2	6.1	6.4	6.7	6.5	6.7
	1979-1982	6.5	6.4	6.6	6.4	6.7	6.7	6.7	6.9
Carbon Dioxide (mg/1)	1979	1.0	0.8	0.8	1.3	1.3	0.7	0.8	0.8
	1980	1.9	2.1	0.8	2.5	0.9	1.1	0.7	1.5
	1981	2.4	2.1	2.3	2.5	1.9	1.9	1.7	1.5
	1982	4.8^{A}	1.1^{C}	3.6^{AB}	2.6^{ABC}	2.8^{ABC}	1.0^{C}	1.9^{BC}	2.2^{BC}
	1979-1982	2.4	1.6	1.8	2.3	1.7	1.3	1.3	1.6
Bicarbonate (mg/1)	1979	38	42	37	36	34	40	36	49
	1980	25	20	18	25	26	14	22	36
	1981	25	36	34	35	40	31	32	37
	1982	34	32	36	24	41	40	44	38
	1979-1982	29	32	30	30	35	30	33	39
Carbonate (mg/1)	1979	6.2	2.3	2.4	4.2	3.7	1.6	2.5	4.7
	1980	3.2	3.5	4.9	2.0	4.2	2.5	1.8	1.2
	1981	3.7	2.1	1.1	2.0	1.9	0.4	0.9	2.2
	1982	0	3.1	.2	0	2.6	2.6	0.2	5.6
	1979-1982	3.3	2.8	2.3	2.1	3.0	1.8	1.3	3.2

Table 21. Continued.

Parameter	Year	0% Control	40% Control Herbicides	40% Control Grass Carp	70% Control Herbicides	70% Control Grass Carp	100% Control Herbicides	100% Control Grass Carp	Fertilization
Specific Conductance (µmhos/cm)	1979	180	170	169	167	160	168	159	202
	1980	161	143	137	159	150	115	127	176
	1981	178	196	189	207	206	177	168	193
	1982	187	214	167	166	209	213	190	213
	1979-1982	175	179	167	175	186	167	161	195
Calcium (mg/1)	1979	25	25	22	21	21	24	23	29
	1980	15	13	12	15	15	21	9.1	20
	1981	16	20	18	22	22	18	17	21
	1982	22	22	22	16	25	26	24	25
	1979-1982	18	20	18	19	21	18	18	23
Potassium	1979	0.3	0.4	0.3	0.4	0.5	0.5	0.5	0.8
	1980	0.2	0.1	0.1	0.3	0.4	0.1	0.1	0.4
	1981	0.4	0.5	0.5	0.9	0.5	1.2	1.0	0.3
	1982	0.5	0.4	0.7	0.4	0.5	1.3	1.5	0.5
	1979-1982	0.3	0.4	0.4	0.5	0.5	0.8	0.8	0.5
Orthosphosphate (mg/1)	1979	.012	.014	.016	.010	.012	.008	.011	.060
	1980	.013	.010	.009	.010	.012	.007	.008	.011
	1981	.017^{B}	.013^{B}	.007^{B}	.011^{B}	.010^{B}	.010^{B}	.007^{B}	.074^{A}
	1982	.002	.022	.001	.001	.006	.004	.003	.022
	1979-1982	.012^{B}	.014^{B}	.008^{B}	.010^{B}	.010^{B}	.007^{B}	.007^{B}	.041^{A}

Table 21. Continued.

Parameter	Year	0% Control	40% Control		70% Control		100% Control		Fertilization
			Herbicides	Grass Carp	Herbicides	Grass Carp	Herbicides	Grass Carp	
Total Phosphorus (mg/1)	1979	.051	.054	.060	.047	.076	.044	.059	.100
	1980	.027	.027	.022	.026	.032	.028	.029	.030
	1981	.023^{A}	.024^{A}	.018^{A}	.022^{A}	.020^{A}	.027^{A}	.019^{A}	.080^{B}
	1982	.023^{AB}	.036^{AB}	.013^{B}	.017^{AB}	.031^{AB}	.040^{AB}	.027^{AB}	.053^{A}
	1979-1982	.029^{B}	.033^{B}	.026^{B}	.027^{B}	.036^{B}	.034^{B}	.031^{B}	.063^{A}
Total Nitrogen (mg/1)	1979	.657	.746	.594	.895	.627	.656	.628	.831
	1980	.542^{AB}	.716^{AB}	.537^{AB}	.673^{AB}	.547^{AB}	.673^{AB}	.474^{B}	.830^{A}
	1981	.521	.641	.551	.695	.610	.781	2.12	.728
	1982	.513	.605	.583	.694	.501	.777	.624	.559
	1979-1982	.548	.670	.559	.720	.568	.731	1.03	.731
Turbidity (NTU)	1979	1.9	1.6	1.6	1.6	1.9	1.5	2.3	2.6
	1980	1.7	1.7	1.8	1.9	2.1	1.6	1.5	1.6
	1981	2.9	2.9	3.6	2.8	2.7	3.0	2.5	2.6
	1982	4.2	3.7	2.1	2.4	3.0	5.0	3.6	4.4
	1979-1982	2.6	2.5	2.4	2.2	2.5	2.9	2.5	2.8
Pheophytin (mg/m^{3})	1979	1.1	2.4	1.2	2.3	1.6	2.5	1.1	3.7
	1980	4.9	3.7	3.1	4.2	3.4	2.9	3.2	5.4
	1981	5.0	3.2	3.1	4.5	2.6	4.5	2.8	3.4
	1982	4.2	5.5	2.1	3.0	2.2	3.8	2.4	6.2
	1979-1982	4.3	3.8	2.7	2.6	3.8	3.6	2.6	4.7
Chlorophyll a (mg/m^{3})	1979	4.5^{B}	6.5^{B}	4.6^{B}	5.8^{B}	8.6^{AB}	6.5^{B}	11^{AB}	17^{A}
	1980	11	9.5	4.8	11	8.4	8.8	7.9	24
	1981	11	8.2	5.4	15	6.3	16	10	13
	1982	13	11	9.8	13	9.6	27	13	18
	1979-1982	11^{AB}	9.0^{AB}	6.0^{B}	12^{AB}	8.1^{AB}	16^{AB}	10^{AB}	18^{A}

Table 21. Continued.

Parameter	Year	0% Control	40% Control		70% Control		100% Control		Fertilization
			Herbicides	Grass Carp	Herbicides	Grass Carp	Herbicides	Grass Carp	
Color (Pt-Co units)	1979	-	-	-	-	-	-	-	-
	1980	50	54	35	59	43	47	30	48
	1981	46	45	35	48	45	43	33	41
	1982	63	37	44	54	49	35	43	40
	1979-1982	52	43	39	53	47	41	38	41
Magnesium (mg/l)	1979	5.3	5.6	5.1	5.1	5.0	5.0	4.5	6.1
	1980	4.3	4.4	4.4	4.4	4.7	3.2	3.8	4.7
	1981	5.0	5.7	5.5	5.6	6.4	4.6	4.8	6.0
	1982	4.9	6.2	4.8	4.1	6.2	5.5	5.4	6.3
	1979-1982	4.8	5.5	5.0	4.9	5.7	4.5	4.6	5.7

No significant treatment differences were found for specific conductance, calcium, magnesium, or potassium (Table 21). With the exception of magnesium (Figure 59), specific conductance (Figure 60), calcium (Figure 61) and potassium (Figure 62) levels varied considerably over time. These temporal changes which are caused by a variety of factors including changes in pond hydrology override any effects of changes in macrophyte vegetation. For example, although not significant at the 0.05 level, potassium concentrations were higher in the ponds where 100% macrophyte control was achieved by herbicides or grass carp. The general rise in potassium concentrations following the removal of macrophytic vegetation agrees well with the findings of Avault et al. (1968) and Lembi et al. (1978). However, significant treatment differences could not be shown because variations in pond water levels caused individual pond values to vary considerably.

Orthophosphate (Figure 63), total phosphorus (Figure 64) and total nitrogen (Figure 65) concentrations varied over time, but were generally similar for all treatments except the fertilization treatment (Table 21). Over the course of this study, orthophosphate and total phosphorus concentrations were significantly higher in the fertilized ponds (Table 21). No significant differences in nutrient concentrations, however, were found between control ponds (0% vegetation control) and 100% vegetation control ponds (Table 21). This suggests removal of macrophytic vegetation by either grass carp of herbicides does not significantly increase nutrient levels in the ponds for any extended period (Table 21).

Chlorophyll a (Figure 66), pheophytin (Figure 67) and turbidity (Figure 68) levels in the ponds were variable. No significant treatment differences, however, were found for turbidity, pheophytin or chlorophyll a levels during 1982 (Table 21). This suggests that the treatments had no major effects on these water quality parameters. Significant

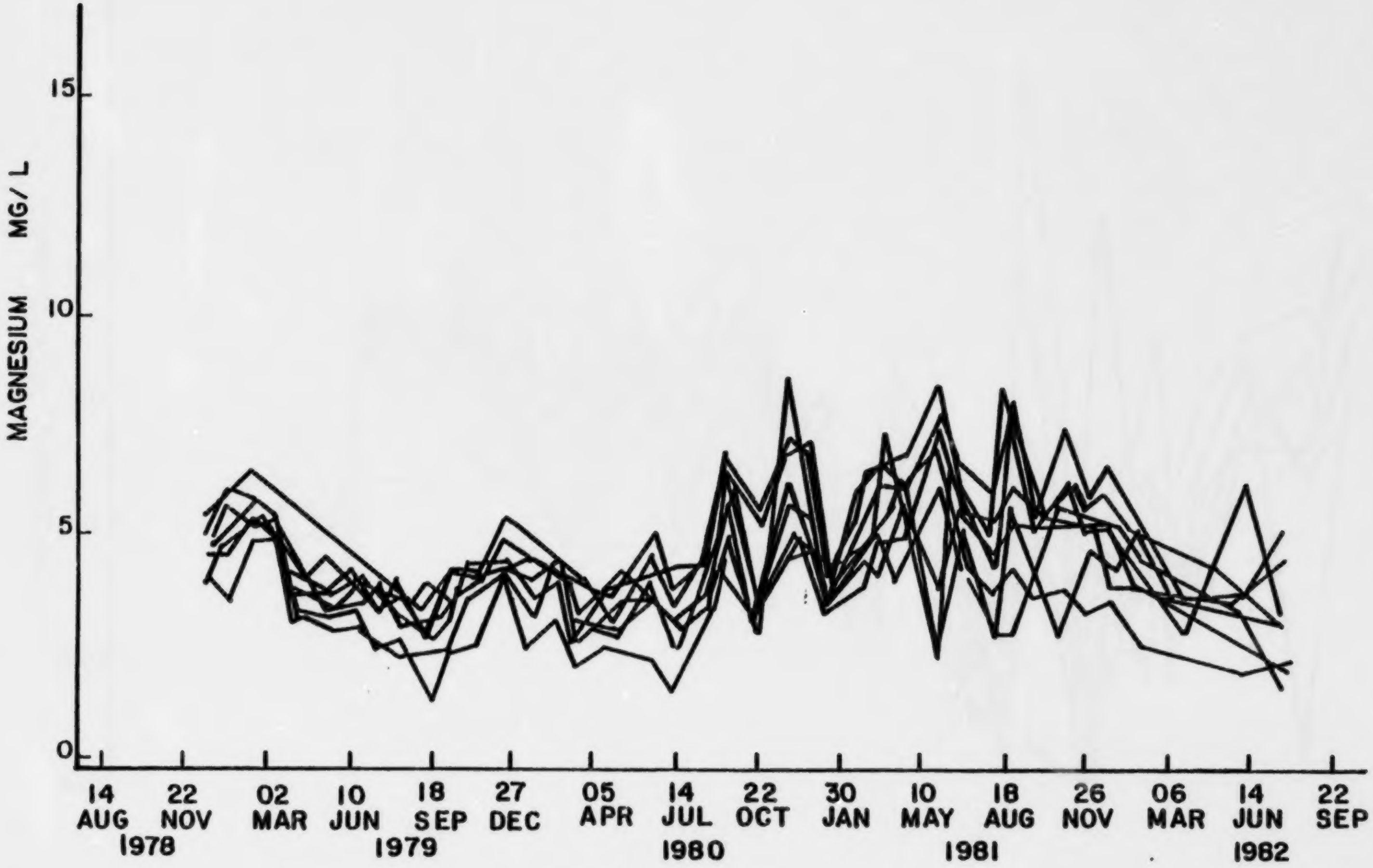

Figure 59. Average monthly magnesium values for all Welaka study ponds, 1978-1982.

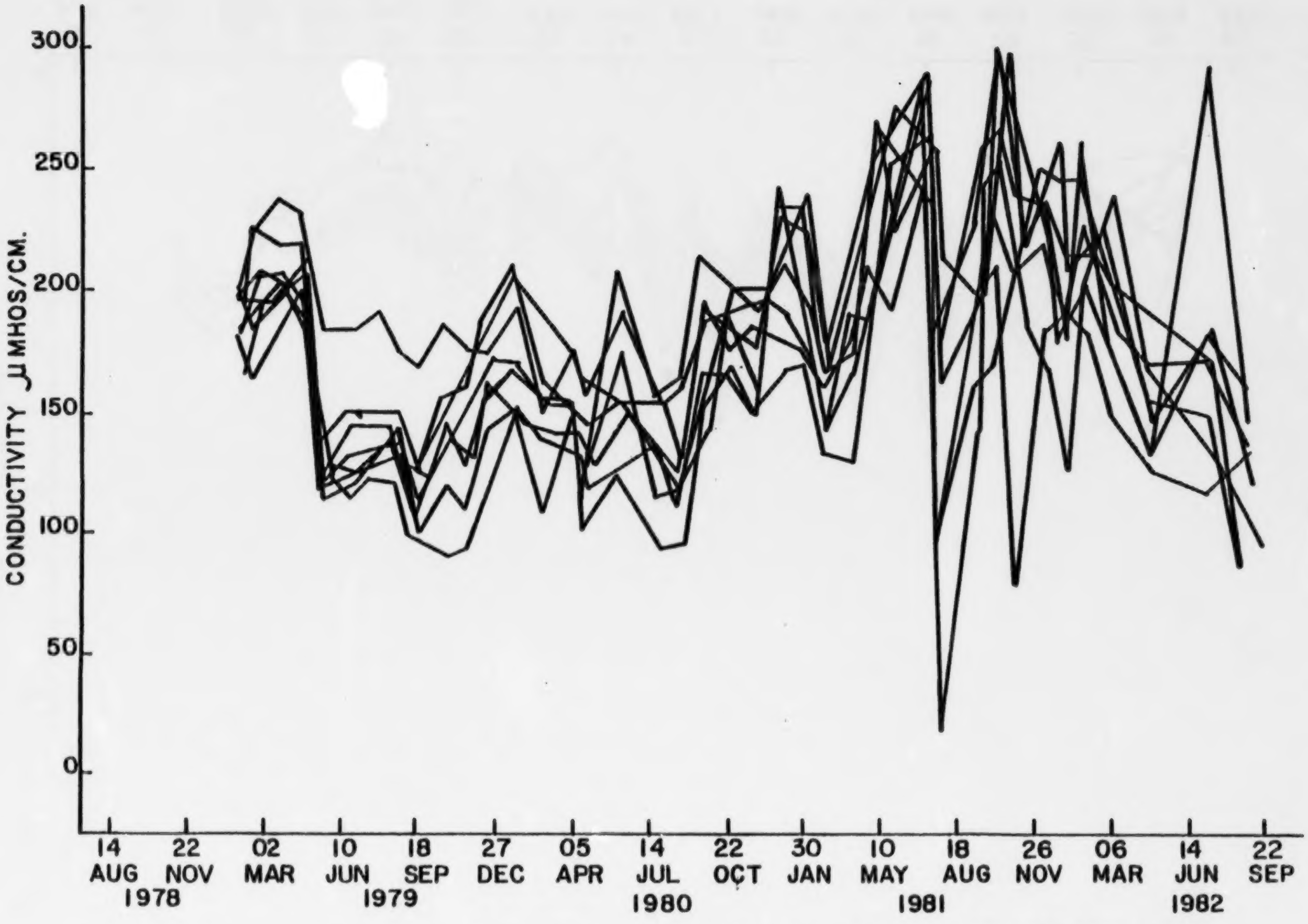

Figure 60. Average monthly conductivity values for all Welaka study ponds, 1978-1982.

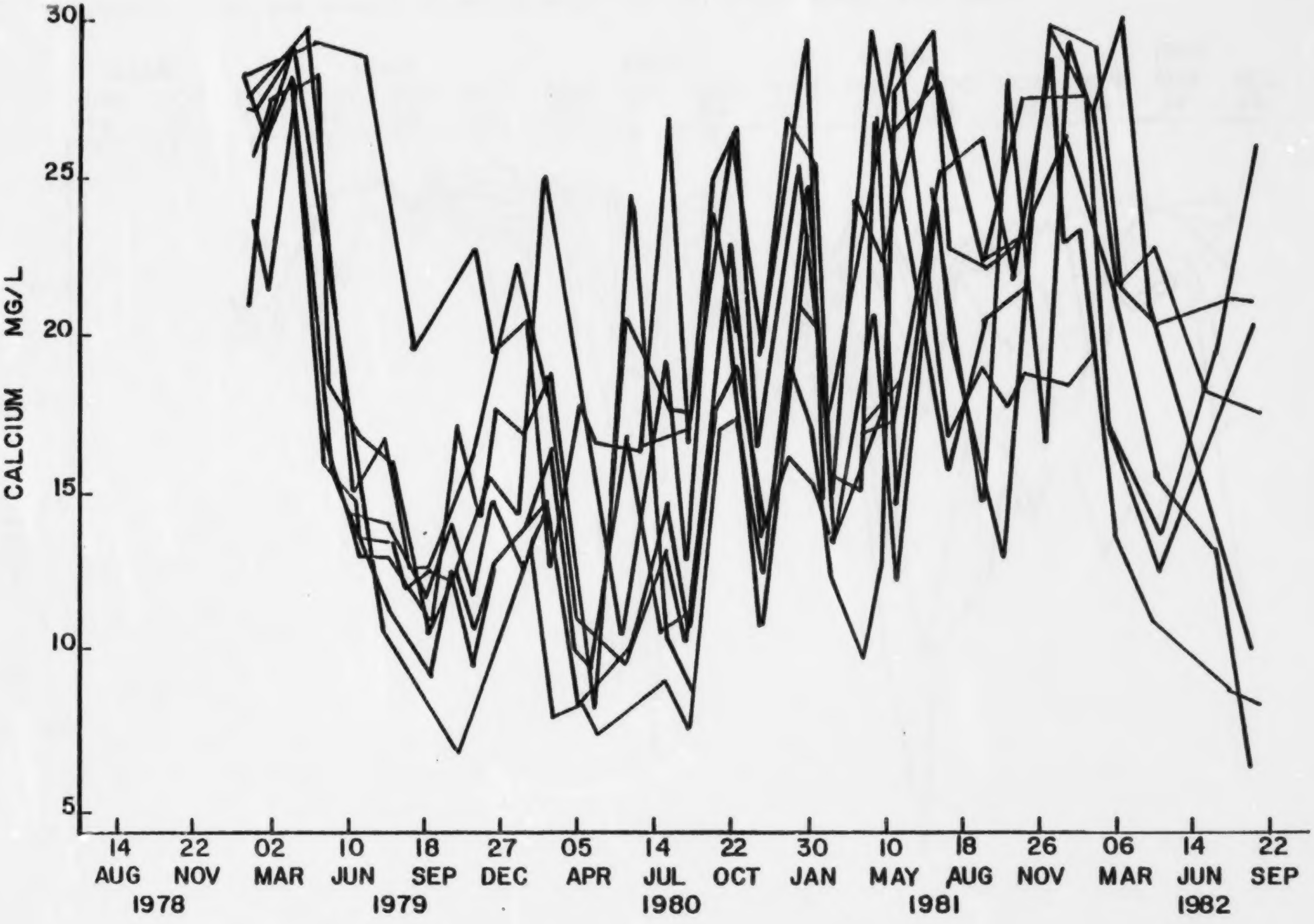

Figure 61. Average monthly calcium values for all Welaka study ponds, 1978-1982.

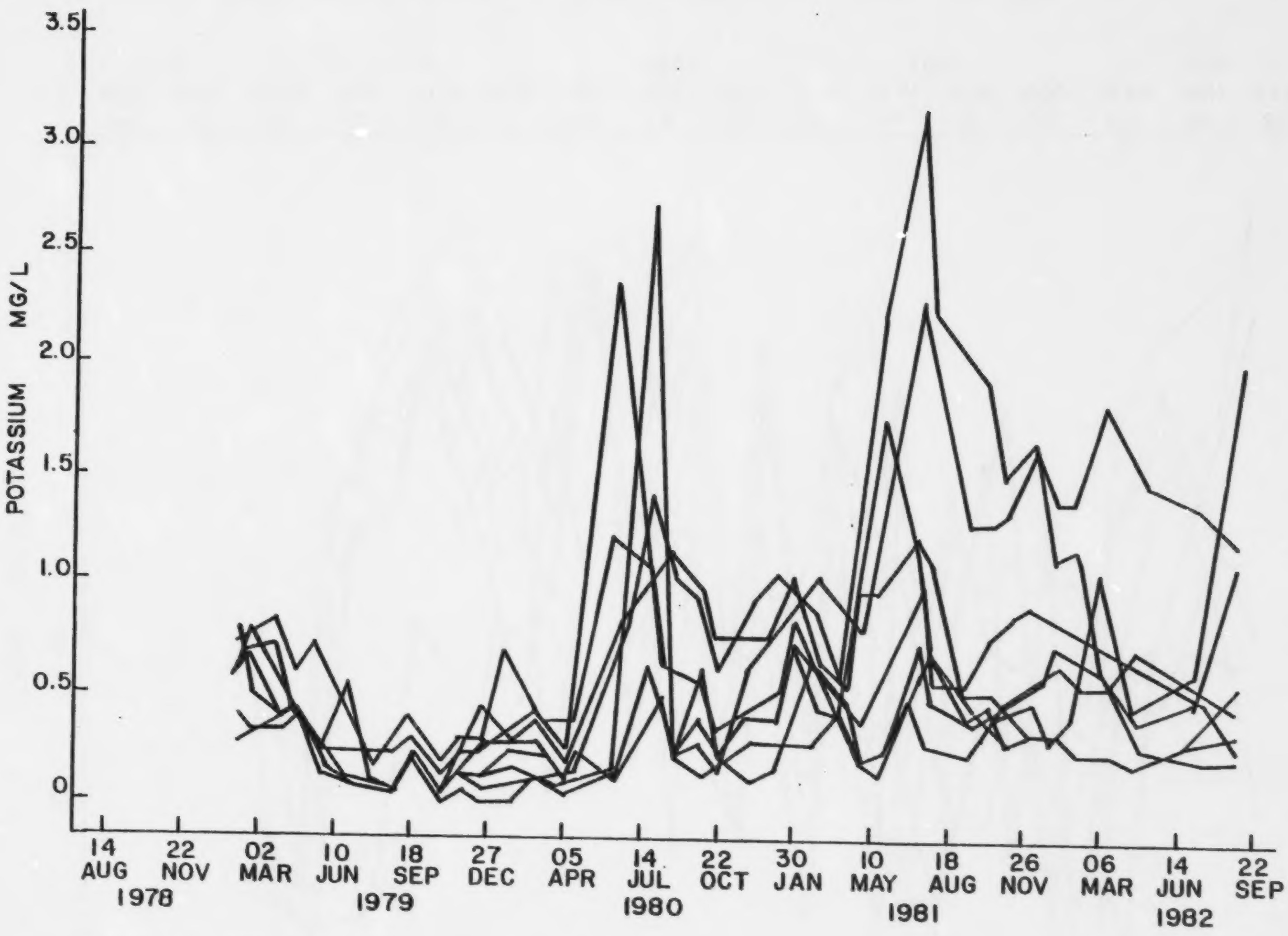

Figure 62. Average monthly potassium values for all Welaka ponds, 1978-1982.

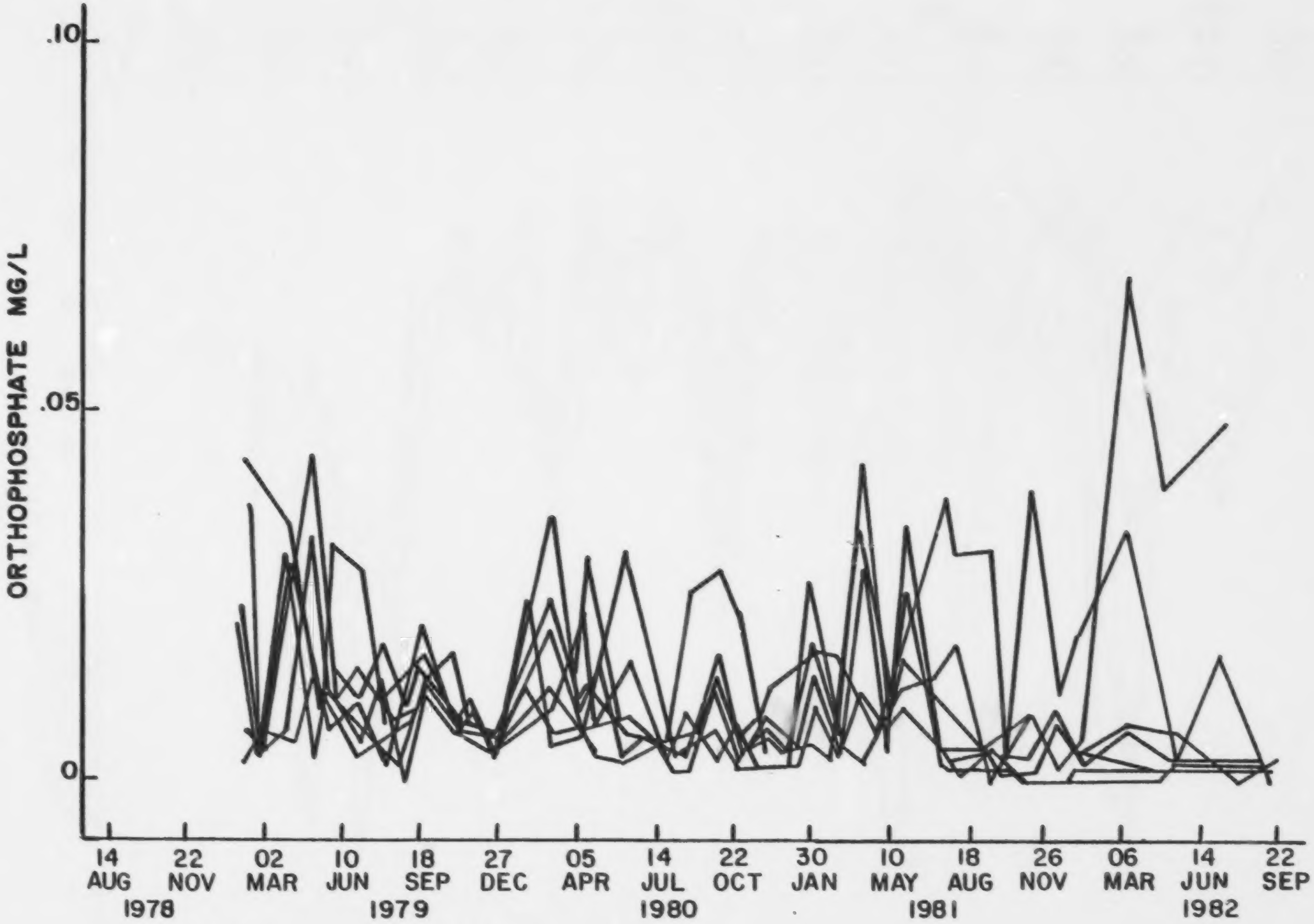

Figure 63. Average monthly orthophosphate values for all Welaka study ponds, 1978-1982.

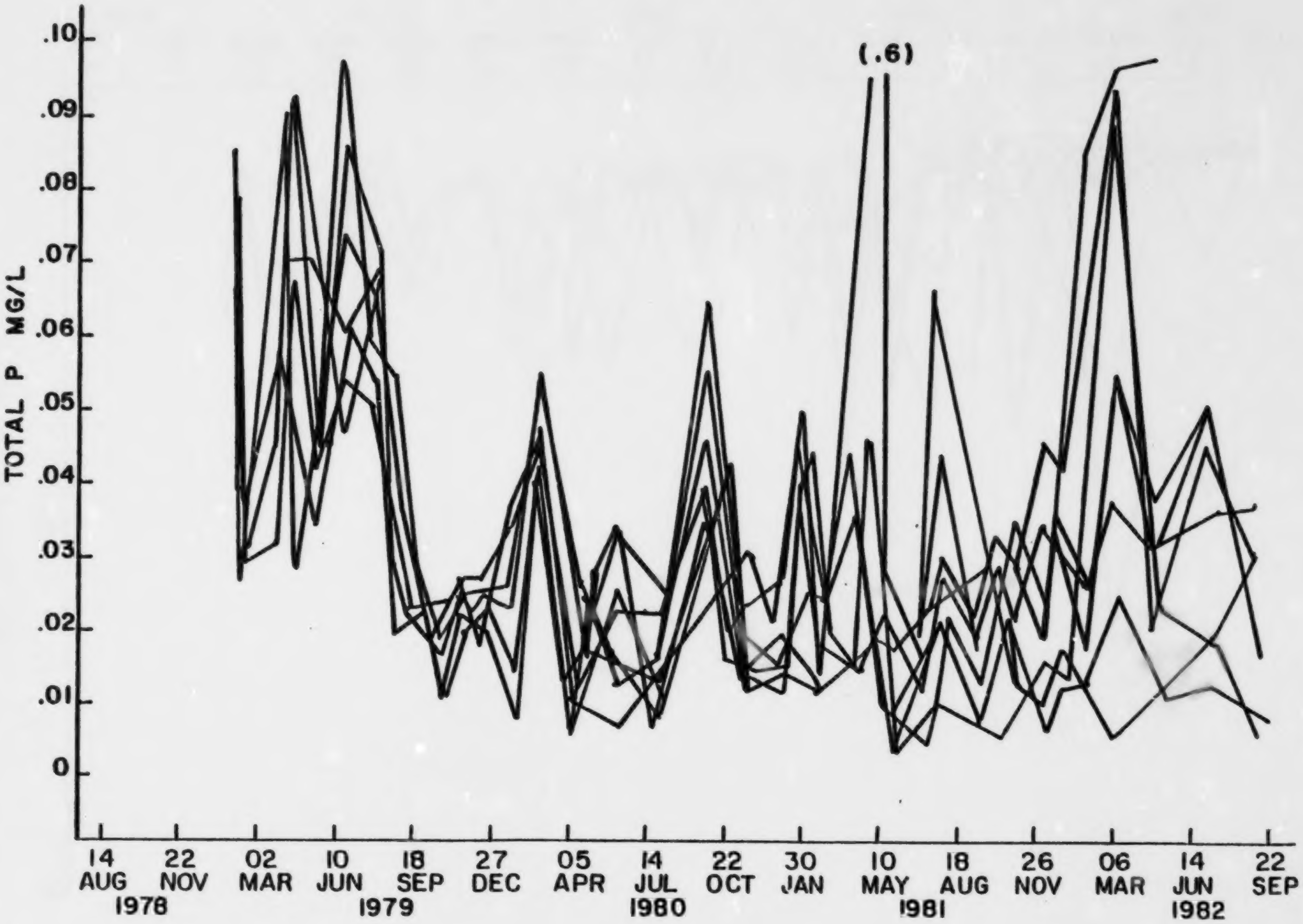

Figure 64. Average monthly total phosphorus values for all Welaka study ponds, 1978-1982.

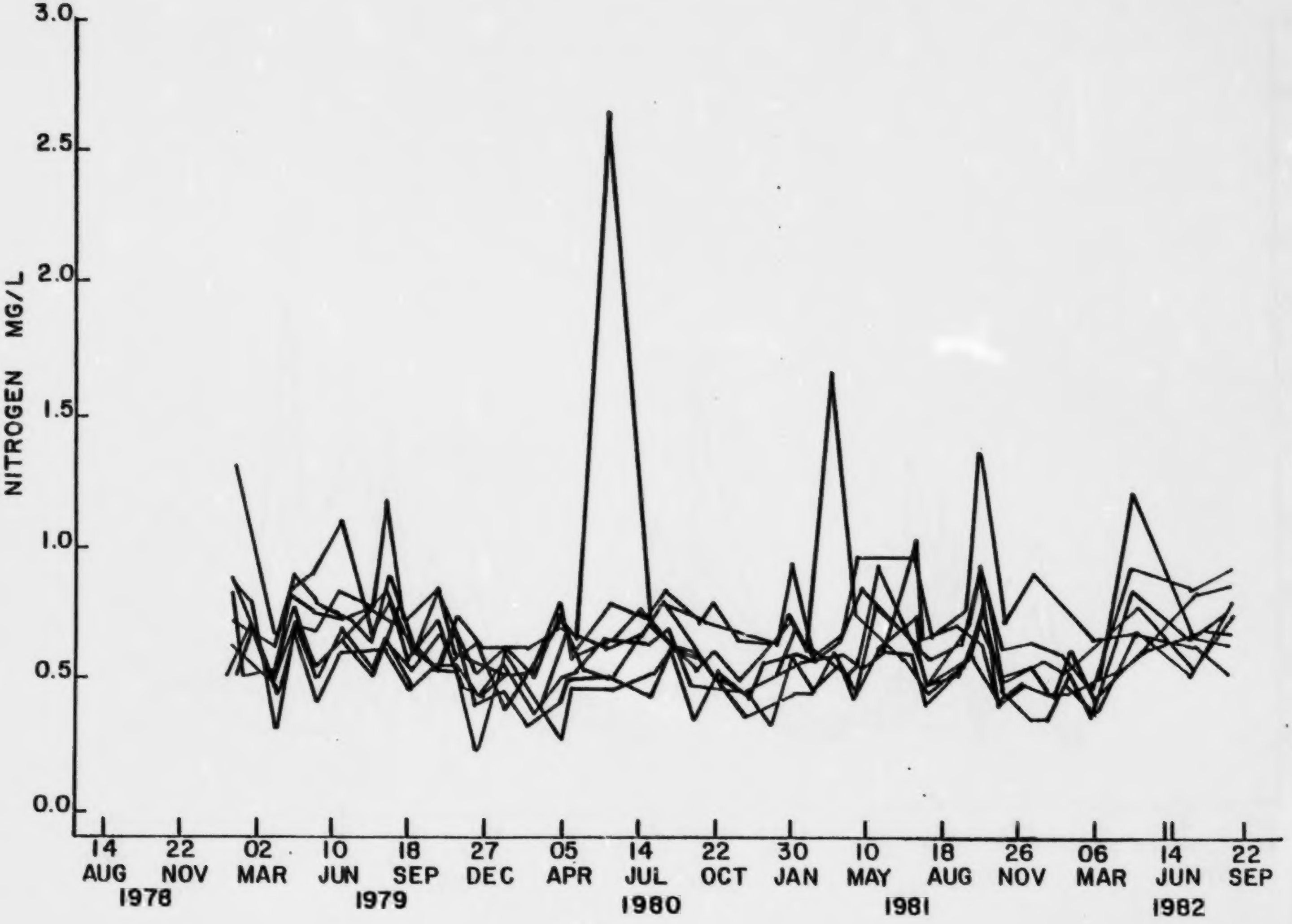

Figure 65. Average monthly nitrogen values for all Welaka study ponds, 1978-1982.

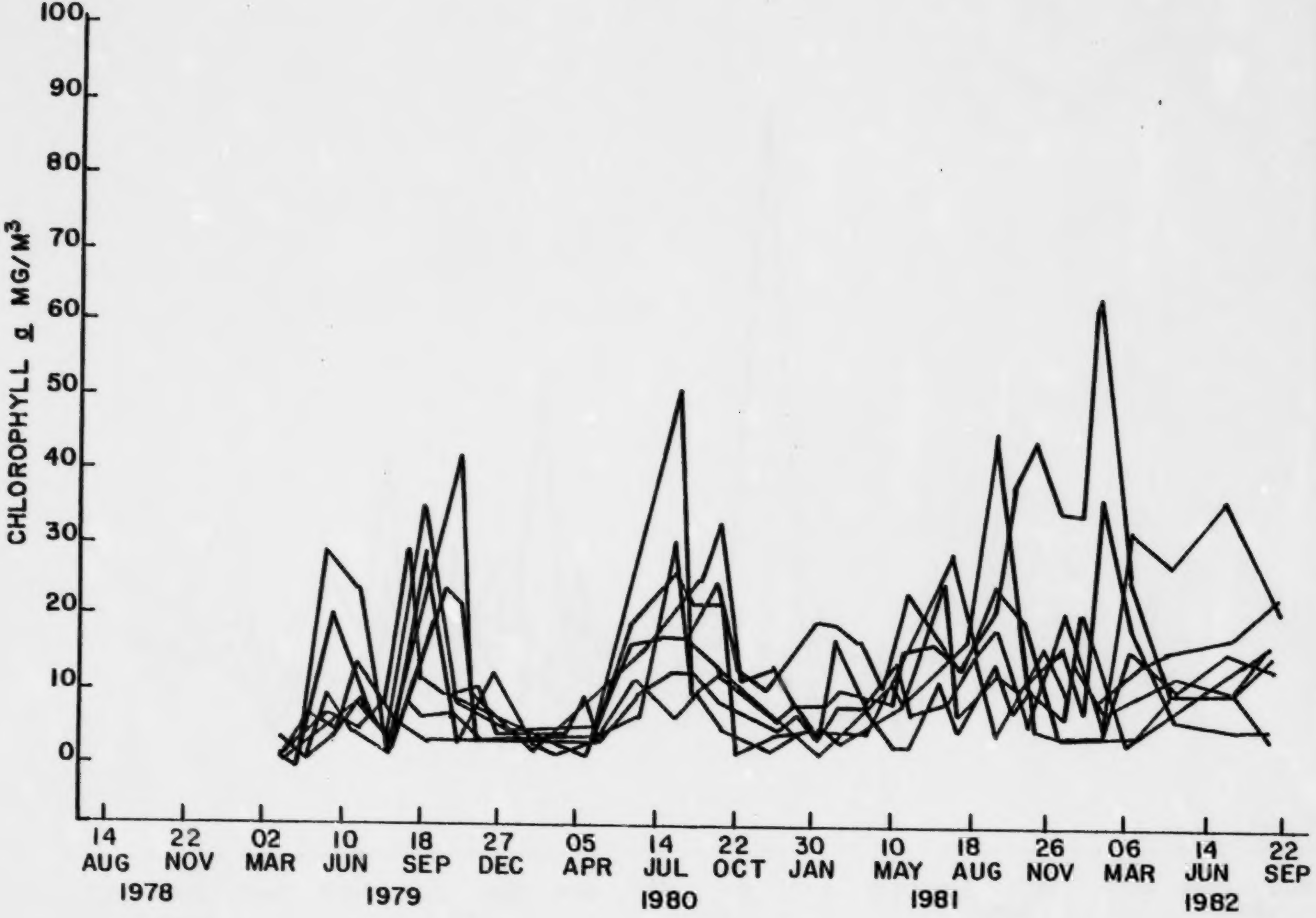

Figure 66. Average monthly chlorophyll a values for all Welaka study ponds, 1978-1982.

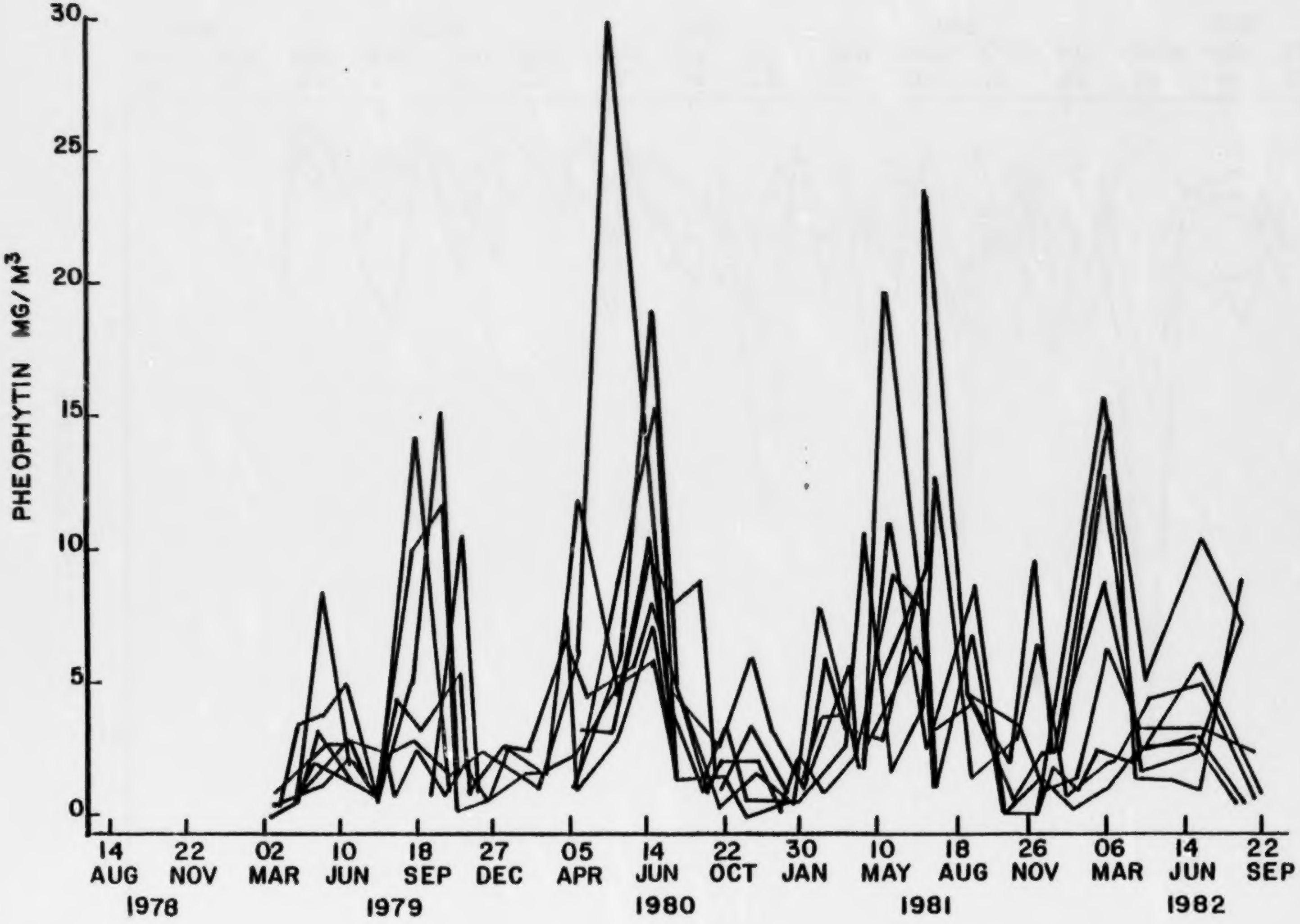

Figure 67. Average monthly pheophytin values for all Welaka study ponds, 1978-1982.

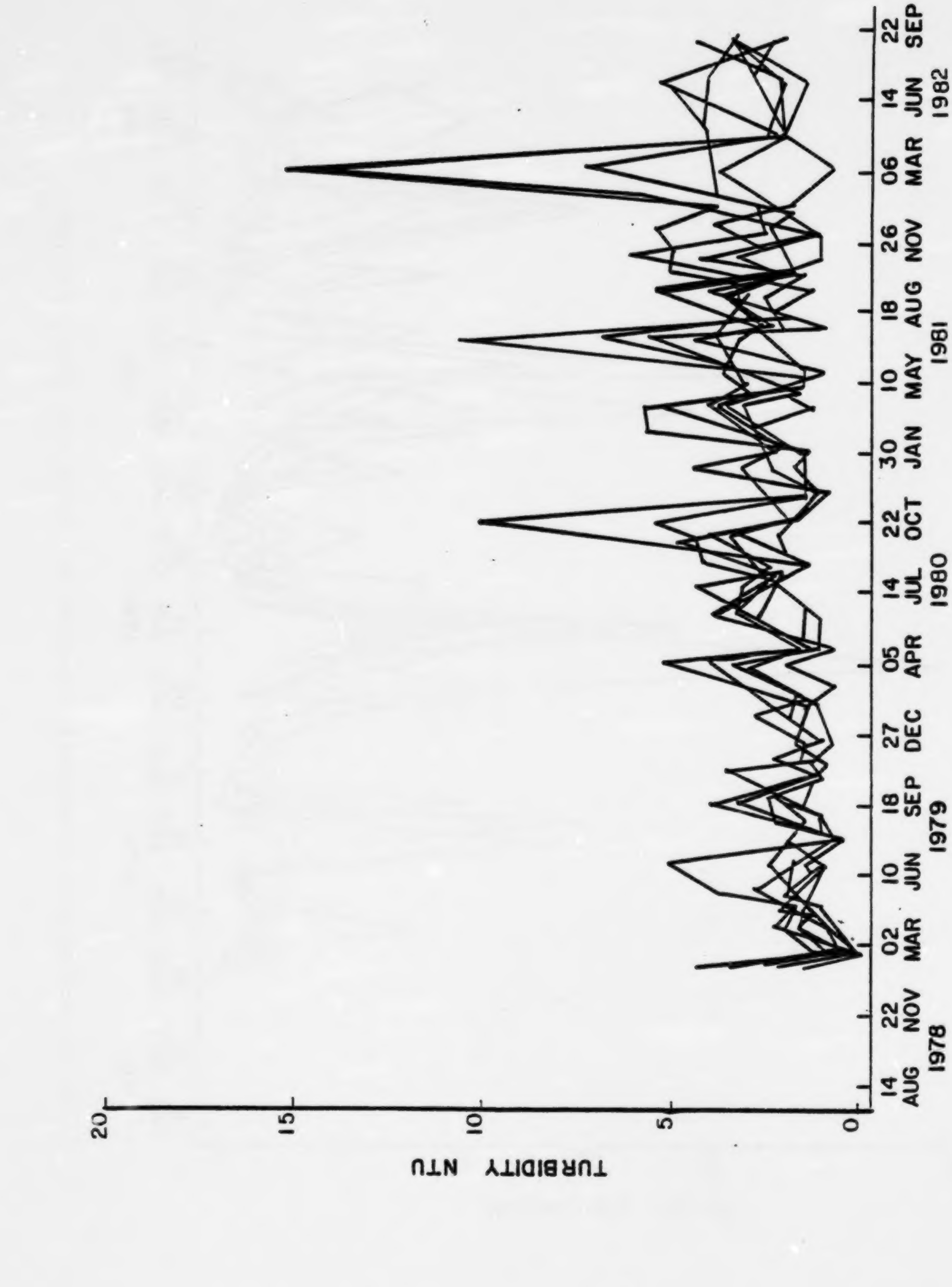

Figure 68. Average monthly turbidity values for all Welaka study ponds, 1978-1982.

differences, however, were measured for pheophytin and chlorophyll in 1979 (Table 21). However, no treatments were applied during the period, therefore, the differences are the result of natural factors.

Similar to the other measured water quality parameters, color values in the ponds were variable (Figure 69). No significant treatment differences, however, were detected (Table 21). This suggests that management of aquatic macrophytes has little effect on the color of water in these aquatic systems.

Diel Chemistry Values - In order to determine the effects of various hydrilla control techniques on soluble carbon and oxygen levels, water chemistry diels were conducted on the Welaka ponds. Water bodies with moderate to high nutrient levels (i.e., mesoeutrophic) usually display photosynthetic rates that can significantly alter soluble carbon and oxygen concentrations of a day:night 24-hr period. Two plant forms, planktonic and filamentous algae and submersed macrophytes, both contribute to these diel fluctuations. In littoral zones, pH fluctuation can range from 6 to 10 over a 24-hour period (Wetzel 1975).

In alkaline lakes, bicarbonate and carbonate ions, are generally formed from the disassociation of calcium carbonate ($CaCO_3$) in water. Thus, an increase in carbon dioxide (CO_2) solubility occurs. Therefore, alkaline lakes tend to be more productive lakes due to the higher availability of carbon for chlorophyll production. Carbon dioxide is the preferred photosynthetic source of inorganic carbon for algae and submersed angiosperms. When bicarbonate ion concentration exceeds CO_2 levels by tenfold, HCO_3 is readily utilized by some plants for photosynthesis. Those plants which can utilize both HCO_3 and CO_2 are more efficient than plants which utilize only CO Hydrilla utilizes CO_2 and HCO_3 in photosynthesis (Van et al. 1976). This is especially true in hardwater lakes where pH levels are higher than 7.5. Free CO_2 dominates the soluble carbon

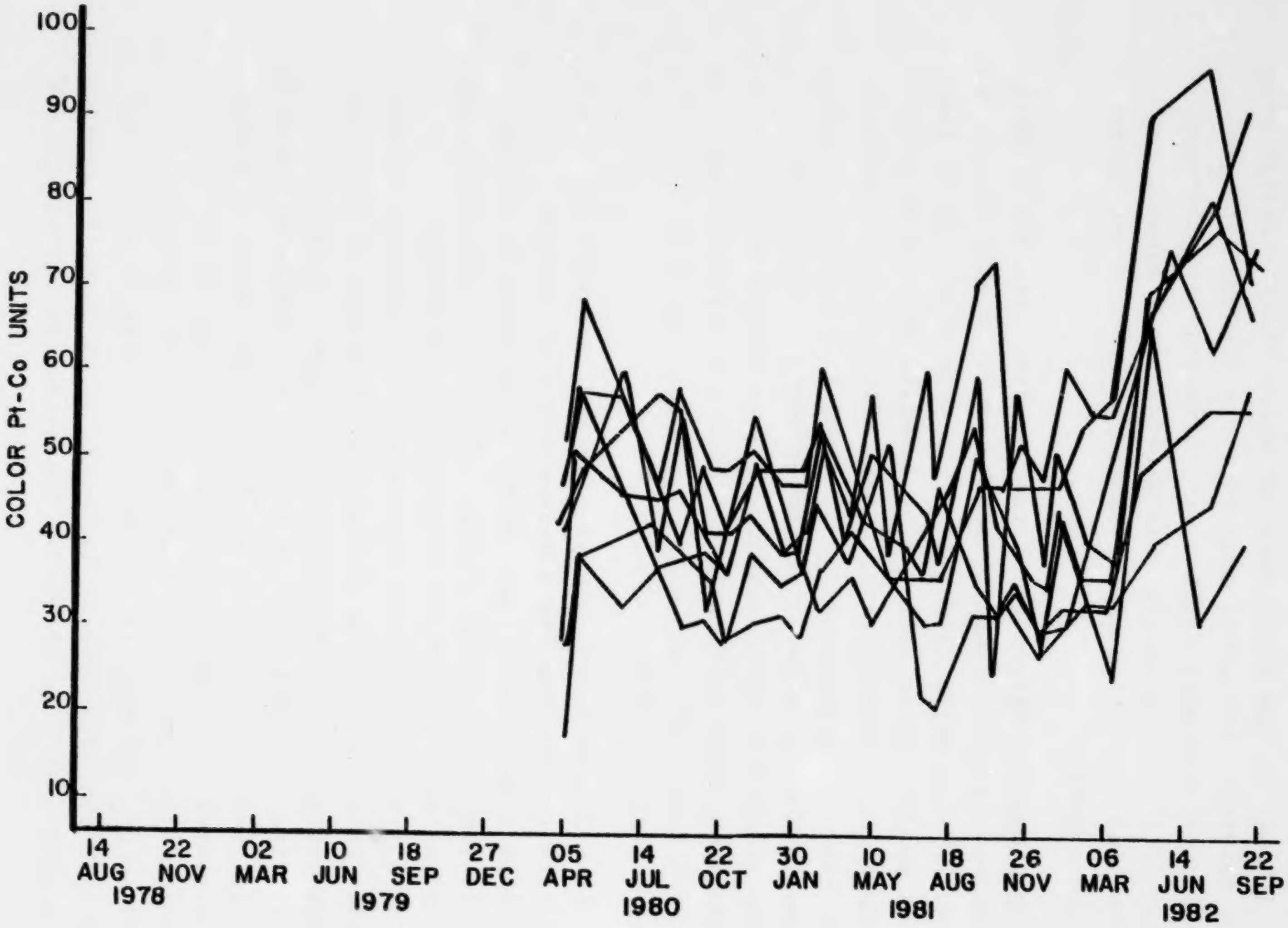

Figure 69. Average monthly color values for all Welaka study ponds 1980-1982.

form in water below pH 5 and between pH 7 and 9, HCO predominates. Above pH 9.5, carbonate ion, generally believed to be an inaccessible carbon form for plant photosynthesis, dominates the soluble carbon in water. Above 8.3, CO_2 in water is non-detectable.

Diel fluctuations of pH, soluble carbon forms and oxygen occurred in Welaka ponds before hydrilla control treatments were initiated in May 1979 (Table 22). In hydrilla and non-hydrilla ponds, pH and soluble carbon fluctuated similarily. After sunrise, hydrilla and algae started photosysnthesis, therefore, soluble carbon was removed from the water. In the morning at 900 hours, a moderate amount of carbon was available for photosynthesis in the form of CO_2 and HCO_3. A by-product of carbon metabolism, oxygen, was released into the water and surface concentrations rose steadily during daylight hours until 1600 hours. In the afternoon, as photosynthesis continues, CO_2 levels declined and CO_2 concentrations increased. Associated with the decline in $CO_2$was an increase in pH. Between 1600 and 2030 hours, photosynthetic activity declined or stopped. CO_2, pH, $CO_2$and oxygen values were unchanged between the 1600 and 2030 hour samples After sunset, all plants began respiration. CO_2 is released from plants into the water, decreasing pH and CO_2 concentrations. Oxygen assimilation occurred as evidenced by a decrease in surface oxygen levels at 0200 and 0600 hours. Peak CO_2 concentrations occurred at 0660 hours (dawn) just before photosynthesis was about to begin again. The observed diel fluctuations of pH, carbon and oxygen in Welaka ponds are typical of most moderately productive water bodies.

Weather conditions, however, can alter the cycle. On cloudy days, the lack of sunlight will decrease or prevent plant photosynthesis from occurring. In extreme cases, plant respiration may occur, thus oxygen can be depleted during daylight hours. This is a common cause of fish kills in the summer time when water temperatures are high and oxygen solubility is low.

Table 22. Mean ($\bar{x}$) pH, soluble carbon and oxygen values from hydrilla infested and non-hydrilla Welaka ponds, May 1979. Hydrilla control has not been initiated in hydrilla ponds (sample size: hydrilla ponds = 21; non-hydrilla ponds = 3).

Time	Parameter	Hydrilla ponds		Non-hydrilla ponds	
		$\bar{x}$	range	$\bar{x}$	range
900 Morning	pH	7.84^a	6.28-9.28	7.91^a	7.20-8.67
	CO_2	1.1^a	0-3.4	0.7^a	0-1.8
	HCO_3^-	25.9^a	7.9-44.7	31.8^a	10.4-62.2
	$CO_3^=$	3.4^a	0-16.6	2.0^a	0-5.9
	SO_2	9.0^a	7.2-11.4	8.6^a	7.8-10.1
1300 Noon	pH	8.08^a	6.79-9.25	8.25^a	7.69-8.97
	CO_2	0.6^a	0-2.2	0.5^a	0-1.2
	HCO_3^-	22.6^a	7.9-42.9	46.9^b	22.9-62.8
	$CO_3^=$	4.7^a	0-24.9	3.6^a	0-10.9
	SO_2	10.5^a	8.3-13.6	10.1^a	8.7-12.7
1600 Mid-afternoon	pH	8.46^a	7.15-9.60	8.46^a	7.73-9.31
	CO_2	0.4^a	0-2.2	0.2^a	0-0.5
	HCO_3^-	24.4^a	7.9-53.7	54.1^b	47.7-61.6
	$CO_3^=$	6.0^a	0-20.8	5.9^a	0-17.8
	SO_2	11.1^a	9.1-14.1	0.6^a	9.0-13.6
2030 Dusk	pH	8.43^a	7.18-9.63	8.37^a	7.55-9.25
	CO_2	0.4^a	0-2.1	0.6^a	0-1.8
	HCO_3^-	22.9^a	8.5-41.1	45.5^a	22.9-62.8
	$CO_3^=$	6.6^a	0-22.6	5.1^a	0-15.4
	SO_2	11.1^a	9.0-14.4	10.5^a	8.6-13.1
200 Night	pH	8.00^a	6.25-9.47	8.20^a	7.55-9.10
	CO_2	0.9^a	0-4.0	0.9^a	0-2.7
	HCO_3^-	25.3^a	9.1-54.3	39.6^a	23.5-62.8
	$CO_3^=$	4.2^a	0-21.3	4.4^a	0-13.1
	SO_2	9.7^a	7.7-14.8	9.1^a	7.6-10.6
600 Dawn	pH	7.88^a	6.45-9.45	7.94^a	6.98-9.05
	CO_2	1.3^a	0-3.7	1.2^a	0-3.0
	HCO_3^-	26.3^a	8.5-46.5	45.3^a	22.3-62.3
	$CO_3^=$	3.1^a	0-16.6	5.5^a	0-16.6
	SO_2	9.1^a	6.2-14.0	8.3^a	7.0-8.6

[a] Mean values in rows followed by the same letter are not significantly different ($P<0.05$).

pH = hydrogen ion x 10^{-pH} g-ions/L

CO_2 = carbon dioxide (mg/L)

HCO_3^- = bicarbonate (mg/L)

$CO_3^=$ = carbonate (mg/L)

SO_2 = surface oxygen (mg/L)

No significant ($P<0.05$) differences in pH, CO_2, CO_2 surface oxygen concentrations occurred between hydrilla and non-hydrilla ponds during all time intervals in May 1979 (Table 22). HCO_3 concentrations were higher in non-hydrilla ponds than hydrilla ponds at 1300 and 1600 hours. High utilization of HCO_3 by hydrilla during daylight hours when pH was rising may have caused the difference between the two pond types. Our data indicates that the photosynthetic systems of hydrilla (a submersed angiosperm) and algae, demonstrate the same cyclic effects on pH, and soluble carbon and oxygen concentrations in homogenous water bodies.

Examination of pH, carbon and oxygen data collected from Welaka ponds during the four water chemistry diels between February 1981 and March 1982, indicated all treatment ponds followed the same basic cyclic patterns explained earlier (Tables 23, 24, 25 and 26). Plant photosynthesis, by hydrilla and/or algae, generally produced no significant ($P<0.05$) differences among all treatments for pH, total alkalinity, CO_2, HCO_3 and CO_2 when specific time intervals were compared except in a few instances. The control methods used to obtain 0, 30 and 60% hydrilla ponds caused no significant ($P<0.05$) differences for pH, total alklinity, CO_2 , HCO_3CO_2 surface O_2 and mid-water O_2 concentrations at specific time intervals. Oxygen and pH values obtained from all the hydrilla control method ponds and treatment level ponds have been shown to be non-detrimental to fish and invertebrates for the ranges observed in each pond. The control ponds which contained 100% hydrilla, however, demonstrated in some instances significantly ($P<0.05$) lower surface and mid-water oxygen concentrations when compared to treatment ponds. Extremely low mid-water oxygen concentrations were recorded in July 1981 when water temperatures were high. Mid-water oxygen levels dropped to less than 2 mg/L during the night in the 100% hydrilla ponds. Thus, oxygen stress to fish might have occurred. We conclude that removal or control of hydrilla by fertilization and mechanical harvesting, grass carp or

Table 23. Mean pH, total alkalinity, soluble carbon and oxygen concentrations from Welaka treatment ponds in February 1981.

Time	Parameter	0% Hydrilla Fert	0% Hydrilla Grass Carp	0% Hydrilla Herb	30% Hydrilla Grass Carp	30% Hydrilla Herb	60% Hydrilla Grass Carp	60% Hydrilla Herb	100% Hydrilla Control
1100 Mid-morning	pH	7.29^{a}	7.18^{a}	7.31^{a}	7.58^{a}	7.09^{a}	7.43^{a}	7.23^{a}	7.26^{a}
	TotALK	48^{a}	45^{a}	46^{a}	58^{a}	59^{a}	53^{a}	62^{a}	50^{a}
	CO_2	1.9^{a}	1.3^{a}	1.7^{a}	1.5^{a}	2.2^{a}	1.5^{a}	1.9^{a}	1.5^{a}
	HCO_3^-	29.2^{a}	26.7^{a}	27.7^{a}	34.8^{a}	35.7^{a}	31.3^{a}	36.9^{a}	29.0^{a}
	$CO_3^=$	0^{a}	0.8^{a}	0^{a}	0.8^{a}	0^{a}	1.2^{a}	0.8^{a}	1.6^{a}
	SO_2	11.4^{b}	11.5^{b}	14.3^{a}	11.3^{b}	12.9^{ab}	12.0^{ab}	10.8^{b}	12.4^{ab}
	MO_2	11.1^{ab}	11.5^{ab}	1.25^{a}	9.8^{b}	10.6^{ab}	10.2^{ab}	10.0^{b}	5.8^{c}
1500 Mid-afternoon	pH	8.02^{a}	7.57^{a}	7.72^{a}	8.04^{a}	7.43^{a}	7.64^{a}	7.76^{a}	7.48^{a}
	TotALK	48^{a}	45^{a}	46^{a}	65^{a}	56^{a}	56^{a}	60^{a}	49^{a}
	CO_2	0.4^{a}	13^{a}	0.7^{a}	0.6^{a}	1.7^{a}	0.8^{a}	1.1^{a}	1.3^{a}
	HCO_3^-	27.6^{a}	23.4^{a}	25.2^{a}	35.4^{a}	30.1^{a}	34.1^{a}	32.6^{a}	22.8^{a}
	$CO_3^=$	7.6^{a}	4.0^{a}	2.8^{a}	4.4^{a}	4.0^{a}	0^{a}	4.0^{a}	3.5^{a}
	SO_2	12.6^{a}	12.7^{a}	14.5^{a}	12.7^{a}	13.7^{a}	12.1^{a}	12.9^{a}	13.8^{a}
	MO_2	12.6^{a}	12.4^{a}	14.0^{a}	10.2^{a}	13.2^{a}	10.0^{a}	12.3^{a}	5.4^{b}
1900 Dusk	pH	7.42^{a}	7.48^{a}	7.48^{a}	7.88^{a}	7.48^{a}	7.83^{a}	7.53^{a}	7.81^{a}
	TotALK	56^{a}	43^{a}	45^{a}	67^{a}	57^{a}	50^{a}	61^{a}	54^{a}
	CO_2	1.4^{a}	1.0^{a}	0.6^{a}	0.7^{a}	1.0^{a}	0.7^{a}	1.0^{a}	0.7^{a}
	HCO_3^-	33.1^{a}	21.1^{a}	23.6^{a}	36.0^{a}	32.3^{a}	24.4^{a}	30.9^{a}	30.5^{a}
	$CO_3^=$	2.0^{a}	5.2^{a}	3.6^{a}	4.8^{a}	2.4^{a}	6.0^{a}	6.0^{a}	2.4^{a}
	SO_2	$15+^{a}$	13.7^{a}	$15+^{a}$	14.2^{a}	$15+^{a}$	13.4^{a}	13.7^{a}	13.2^{a}
	MO_2	13.2^{a}	12.4^{a}	14.1^{a}	12.0^{a}	13.4^{a}	11.8^{a}	12.9^{a}	6.6^{a}
000 Midnight	pH	7.23^{a}	7.34^{a}	7.28^{a}	7.44^{a}	7.04^{a}	7.46^{a}	7.10^{a}	7.20^{a}
	TotALK	49^{a}	51^{a}	44^{a}	61^{a}	55^{a}	54^{a}	62^{a}	46^{a}
	CO_2	2.0^{a}	1.0^{a}	0.8^{a}	1.5^{a}	2.0^{a}	0.7^{a}	1.7^{a}	1.8^{a}
	HCO_3^-	30.1^{a}	30.5^{a}	27.0^{a}	35.6^{a}	30.5^{a}	30.7^{a}	37.6^{a}	28.2^{a}
	$CO_3^=$	0^{a}	0.4^{a}	0^{a}	1.6^{a}	0^{a}	2.0^{a}	0^{a}	0^{a}
	SO_2	13.5^{a}	13.6^{a}	14.1^{a}	11.1^{a}	12.4^{a}	12.3^{a}	12.0^{a}	11.0^{a}
	MO_2	7.7^{a}	11.1^{a}	13.2^{a}	7.5^{a}	11.3^{a}	10.8^{a}	10.7^{a}	5.9^{a}
	pH	6.79^{a}	6.89^{a}	6.82^{a}	7.05^{a}	6.71^{a}	6.95^{a}	6.73^{a}	6.93^{a}
	TotALK	51^{a}	50^{a}	50^{a}	69^{a}	58^{a}	52^{a}	66^{a}	57^{a}
	CO_2	2.1^{a}	0.8^{a}	1.3^{a}	2.1^{a}	2.9^{a}	1.3^{a}	2.0^{a}	1.1^{a}
	HCO_3^-	31.1^{a}	30.3^{a}	30.3^{a}	41.9^{a}	35.6^{a}	31.7^{a}	40.6^{a}	34.6^{a}
	$CO_3^=$	0^{a}	0^{a}	0	0	0	0	0	0
	SO_2	11.3^{a}	11.4^{a}	14.1^{a}	13.9^{a}	11.8^{a}	10.9^{a}	8.3^{a}	9.7^{a}
	MO_2	10.1^{ab}	10.1^{ab}	12.5^{ab}	9.4^{ab}	9.2^{ab}	8.7^{ab}	7.8^{b}	5.9^{b}

[a] Mean values in rows followed by the same letter are not significantly different ($P<0.05$).

pH = hydrogen ion x 10^{-pH} g-ions/L

TotALK = total alkalinity (mg/L)

CO_2 = carbon dioxide (mg/L)

HCO_3^- = bicarbonate (mg/L)

$CO_3^=$ = carbonate (mg/L)

SO_2 = surface oxygen (mg/L)

MO_2 = mid-water oxygen (mg/L)

Table 24. Mean pH, total alkalinity, soluble carbon and oxygen concentrations from Welaka treatment ponds in July 1981.

		0% Hydrilla			30% Hydrilla		60% Hydrilla		100% Hydrilla
ime	Parameter	Fert	Grass Carp	Herb	Grass Carp	Herb	Grass Carp	Herb	Control
1100 Mid-morning	pH	7.75^{a}	7.43^{a}	7.43^{a}	7.40^{a}	7.59^{a}	7.06^{a}	7.78^{a}	6.85^{a}
	TotALK	102^{a}	96^{a}	87^{a}	91^{a}	78^{a}	72^{a}	57^{a}	66^{a}
	CO_2	2.6	1.9^{a}	2.7^{a}	2.7^{a}	1.2^{a}	2.8^{a}	1.3^{a}	5.7^{b}
	HCO_3^-	59.1^{a}	58.4^{a}	52.9^{a}	55.3^{a}	43.4^{a}	43.6^{a}	26.3^{a}	39.4^{a}
	$CO_3^=$	2.8^{ab}	0^{a}	0^{a}	0	4.0^{ab}	0^{a}	8.4^{a}	0^{a}
	SO_2	9.9^{a}	7.4^{a}	9.0^{a}	7.3^{a}	11.6^{a}	8.5^{a}	10.1^{a}	10.3^{a}
	MO_2	5.2^{ab}	6.9^{a}	8.2^{a}	5.0^{ab}	7.2^{a}	6.5^{a}	5.4^{ab}	2.2^{b}
1530 Mid-afternoon	pH	8.52^{a}	7.75^{a}	7.83^{a}	7.77^{a}	7.96^{a}	7.57^{a}	7.84^{a}	6.99^{a}
	TotALK	95^{a}	97^{a}	85^{a}	87^{a}	73^{a}	69^{a}	65^{a}	57^{a}
	CO_2	$.7^{a}$	1.1^{a}	0.9^{a}	2.1^{a}	0.6^{a}	$.7^{a}$	1.2^{a}	2.6^{a}
	HCO_3^-	48.2^{a}	59.3^{a}	50.0^{a}	50.8^{a}	38.6^{a}	40.9^{a}	29.3^{a}	39.6^{a}
	$CO_3^=$	9.6^{a}	0^{a}	1.6^{a}	1.6^{a}	6.0^{a}	1.2^{a}	5.5^{a}	0^{a}
	SO_2	13.0^{a}	9.2^{a}	10.4^{a}	10.5^{a}	12.4^{a}	12.5^{a}	12.3^{a}	11.1^{a}
	MO_2	7.7^{ab}	7.2^{ab}	11.0^{a}	8.0^{ab}	8.2^{ab}	9.7^{a}	7.0^{ab}	2.0^{b}
2000 Dusk	pH	8.52^{ab}	7.69^{a}	7.91^{a}	7.90^{a}	7.98^{a}	7.89^{a}	7.97^{a}	6.67^{a}
	TotALK	93	93	86	86	71	69	52	66
	CO_2	0.3^{b}	2.1^{ab}	0.7^{b}	1.9^{ab}	0.4^{b}	0.4^{b}	0.4^{b}	3.7^{a}
	HCO_3^-	50.0^{a}	56.7^{a}	50.0^{a}	49.0^{a}	36.8^{a}	40.2^{a}	25.8^{a}	40.2^{a}
	$CO_3^=$	6.8^{a}	0^{a}	1.6^{a}	3.2^{a}	6.4^{a}	1.8^{a}	5.6^{a}	0^{a}
	SO_2	14.0^{a}	9.5^{a}	12.2^{a}	10.3^{a}	12.1^{a}	11.4^{a}	11.9^{a}	9.9^{a}
	MO_2	5.7^{ab}	9.1^{ab}	12.3^{a}	8.0^{ab}	10.3^{a}	8.3^{ab}	6.5^{ab}	2.3^{b}
000 Midnight	pH	7.62^{a}	7.35^{a}	7.55^{a}	7.23^{a}	7.51^{a}	6.90^{a}	7.25^{a}	6.39^{a}
	TotALK	94^{a}	94^{a}	86^{a}	87^{a}	70^{a}	69^{a}	56^{a}	66^{a}
	CO_2	2.6^{a}	1.9^{a}	0.9^{a}	3.1^{a}	1.2^{a}	2.6^{a}	1.9^{a}	6.6^{b}
	HCO_3^-	56.3^{a}	57.3^{a}	52.4^{a}	52.8^{a}	39.0^{a}	41.8^{a}	29.9^{a}	40.2^{a}
	$CO_3^=$	0.8^{a}	0^{a}	0^{a}	0^{a}	3.6^{a}	0^{a}	4.0^{a}	0^{a}
	SO_2	7.4^{ab}	7.2^{ab}	11.0^{a}	6.1^{b}	4.9^{b}	7.2^{ab}	6.2^{b}	$5,7^{b}$
	MO_2	4.5^{b}	6.0^{ab}	10.4^{a}	6.4^{ab}	6.4^{ab}	5.6^{ab}	4.1^{b}	1.6^{b}
600 Dawn	pH	7.29^{a}	7.30^{a}	7.34^{a}	7.15^{a}	7.17^{a}	6.8^{a}	7.13^{a}	6.59^{a}
	TotALK	104^{a}	98^{a}	89^{a}	94^{a}	77^{a}	82^{a}	58^{a}	79^{a}
	CO_2	4.1^{b}	2.5^{b}	2.9^{b}	5.9^{ab}	2.2^{b}	4.6^{ab}	3.4^{b}	8.1^{a}
	HCO_3^-	63.2^{a}	59.8^{a}	54.5^{a}	57.3^{a}	47.1^{a}	50.0^{a}	35.4^{a}	47.9^{a}
	$CO_3^=$	0	0	0	0	0	0	0	0
	SO_2	4.8^{ab}	5.4^{ab}	7.8^{a}	4.4^{ab}	4.2^{ab}	3.4^{b}	3.3^{b}	2.1^{b}
	MO_2	4.1^{abc}	5.0^{a}	7.2^{a}	3.9^{abc}	3.7^{bc}	2.1^{bc}	1.8^{bc}	0.7^{c}

[a] Mean values in rows followed by the same letter are not significantly different ($P<0.05$).
pH = hydrogen ion x 10^{-pH} g-ions/L
TotALK = total alkalinity (mg/L)
CO_2 = carbon dioxide (mg/L)
HCO_3^- = bicarbonate (mg/L)
$CO_3^=$ = carbonate (mg/L)
SO_2 = surface oxygen (mg/L)
MO_2 = mid-water oxygen (mg/L)

Table 25. Mean pH, total alkalinity and soluble carbon concentrations from Welaka treatment ponds in October 1981.

Time	Parameter	0% Hydrilla			30% Hydrilla		60% Hydrilla		100% Hydrilla
		Fert	Grass Carp	Herb	Grass Carp	Herb	Grass Carp	Herb	Control
1100 Mid-morning	pH	6.99^{abc}	6.96^{bc}	7.79^{a}	7.07^{ab}	6.36^{bc}	6.60^{bc}	7.20^{ab}	6.19^{c}
	TotALK	101^{a}	82^{a}	92^{a}	108^{a}	49^{a}	80^{a}	107^{a}	32^{a}
	CO_2	5.1^{b}	3.3^{b}	0.7^{a}	3.1^{b}	4.1^{b}	4.8^{b}	3.3^{b}	9.3^{c}
	HCO_3^-	61.4^{a}	49.7^{a}	56.0^{a}	65.8^{a}	29.6^{a}	48.9^{a}	60.9^{a}	19.5^{a}
	$CO_3^=$	0	0	0	0	0	0	0	0
1500 Mid-afternoon	pH	7.29^{abc}	7.42^{abc}	8.22^{a}	7.45^{ab}	6.60^{cd}	6.91^{bcd}	7.64^{ab}	6.28^{d}
	TotALK	105^{a}	79^{a}	94^{a}	115^{a}	49^{a}	81^{a}	104^{a}	32^{a}
	CO_2	3.6^{b}	2.4^{bc}	0.1^{c}	2.9^{bc}	3.1^{bc}	4.2^{b}	1.7^{bc}	7.5^{c}
	HCO_3^-	64.2^{a}	48.0^{a}	53.5^{a}	70.1^{a}	30.1^{a}	49.1^{a}	63.4^{a}	19.5^{a}
	$CO_3^=$	0	0	0.1	0	0	0	0	0
1900 Dusk	pH	7.50^{ab}	7.37^{ab}	8.14^{a}	7.48^{ab}	6.72^{ab}	6.76^{ab}	7.69^{a}	6.20^{b}
	TotALK	94^{a}	83^{a}	91^{a}	105^{a}	50^{a}	79^{a}	102^{a}	29^{a}
	CO_2	2.0^{a}	1.3^{a}	0.3^{a}	1.4^{a}	1.7^{a}	2.1^{a}	1.1^{a}	5.0^{b}
	HCO_3^-	55.9	50.4	51.6	64.2	30.2	48.2	62.0	17.4
	$CO_2^=$	1.2	0	0	0	0	0	0	0
000 Midnight	pH	7.09^{ab}	7.30^{a}	7.60^{a}	7.29^{a}	6.45^{ab}	7.00^{ab}	7.52^{a}	6.04^{b}
	TotALK	96^{a}	81^{a}	92^{a}	103^{a}	49^{a}	80^{c}	97^{a}	30^{a}
	CO_2	5.0^{ab}	3.8^{ab}	0.8^{b}	3.6^{ab}	2.9^{ab}	6.3^{a}	2.1^{ab}	5.4^{ab}
	HCO_3^-	58.3^{a}	49.6^{a}	50.4^{a}	62.7^{a}	29.9^{a}	48.5^{a}	59.3^{a}	18.3^{a}
	$CO_2^=$	0	0	5.6	0	0	0	0	0
700 Dawn	pH	6.46^{abc}	6.69^{a}	6.96^{a}	6.72^{a}	5.70^{ab}	6.24^{abc}	6.62^{ab}	5.58^{c}
	TotALK	101^{a}	88^{a}	105^{a}	100^{a}	54^{a}	81^{a}	99^{a}	34^{a}
	CO_2	6.0^{ab}	3.9^{b}	3.2^{b}	4.0^{b}	2.9^{b}	5.6^{ab}	3.8^{b}	8.9^{a}
	HCO_3^-	61.4^{a}	53.7^{a}	63.8^{a}	61.0^{a}	32.9	49.4^{a}	60.2^{a}	20.7^{a}
	$CO_2^=$	0	0	0	0	0	0	0	0

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[a] Mean values in rows followed by the same letter are not significantly different (P 0.05)

pH = hydrogen ion x 10^{-pH} g-ions/L

TotALK = total alkalinity (mg/L)

CO_2 = carbon dioxide (mg/L)

HCO_3^- = bicarbonate (mg/L)

$CO_3^=$ = carbonate (mg/L)

Table 26. Mean pH, total alkalinity, soluble carbon and oxygen concentrations from Welaka ponds in March 1982.

Time	Parameter	0% Hydrilla			30% Hydrilla		60% Hydrilla		100% Hydrilla
		Fert	Grass Carp	Herb	Grass Carp	Herb	Grass Carp	Herb	Control
1100 Mid-morning	pH	8.05^{a}	6.86^{ab}	7.75^{ab}	7.39^{ab}	6.63^{ab}	6.89^{ab}	7.68^{ab}	6.54^{b}
	TotALK	53^{a}	69^{a}	54^{a}	70^{a}	40^{a}	89^{a}	49^{a}	64^{a}
	CO_2	0.7^{c}	3.0^{ab}	1.4^{bc}	3.0^{ab}	3.7^{a}	3.3^{ab}	0.7^{c}	4.3^{a}
	HCO_3^-	38.6^{a}	42.1^{a}	30.9^{a}	41.1^{a}	24.2^{a}	54.0^{a}	36.3^{a}	29.2^{a}
	SO_2	12.5^{a}	10.3^{ab}	10.3^{ab}	8.5^{b}	11.3^{ab}	9.1^{b}	12.9^{a}	10.1^{ab}
	MO_2	10.2^{ab}	9.3^{ab}	6.9^{b}	7.3^{b}	9.1^{ab}	8.5^{ab}	11.1^{a}	7.4^{b}
1500 Mid-morning	pH	8.47^{a}	6.79^{ab}	7.76^{ab}	7.27^{ab}	5.81^{b}	6.74^{ab}	8.16^{a}	7.06^{ab}
	TotALK	51^{a}	66^{a}	52^{a}	70^{a}	37^{a}	74^{a}	52^{a}	64^{a}
	CO_2	0.4^{b}	1.7^{a}	0.3^{b}	1.3^{ab}	2.4^{ab}	2.6^{a}	0.4^{b}	2.2^{a}
	HCO_3^-	47.0^{a}	40.2^{a}	40.6^{a}	51.3^{a}	22.6^{a}	45.1^{a}	41.3^{a}	29.0^{a}
	SO_2	14.7^{a}	10.1^{ab}	12.2^{ab}	9.8^{b}	10.7^{ab}	8.9^{b}	13.4^{ab}	10.1^{b}
	MO_2	10.0^{a}	9.3^{a}	10.8^{a}	11.8^{a}	10.0^{a}	7.4^{a}	10.1^{a}	5.6^{a}
1900 Dusk	pH	8.60^{a}	7.48^{a}	8.23^{a}	8.08^{a}	6.80^{a}	7.70^{a}	8.15^{a}	7.40^{a}
	TotALK	52^{a}	69^{a}	52^{a}	70^{a}	37^{a}	87^{a}	49^{a}	60^{a}
	CO_2	0.6^{a}	1.7^{a}	0.4^{a}	1.9^{a}	2.2^{a}	1.7^{a}	0.4^{a}	1.7^{a}
	HCO_3^-	48.6^{a}	41.9^{a}	50.2^{a}	51.3^{a}	22.3^{a}	53.0^{a}	47.5^{a}	36.6^{a}
	SO_2	11.1^{a}	11.5^{a}	10.2^{a}	10.4^{a}	11.3^{a}	13.8^{a}	12.4^{a}	11.4^{a}
	MO_2	8.3^{a}	9.8^{a}	7.8^{a}	7.4^{a}	8.8^{a}	6.7^{a}	10.9^{a}	7.9^{a}
2400 Midnight	pH	8.18^{a}	7.28^{a}	7.89^{a}	7.26^{a}	6.66^{a}	7.49^{a}	7.73^{a}	6.77^{a}
	TotALK	51^{a}	69^{a}	54^{a}	67^{a}	35^{a}	88^{a}	53^{a}	63^{a}
	CO_2	1.4^{a}	1.7^{a}	0.7^{a}	4.3^{a}	3.2^{a}	3.2^{a}	1.0^{a}	43^{a}
	HCO_3^-	47.0^{a}	59.1^{a}	41.6^{a}	44.4^{a}	21.3^{a}	53.7^{a}	41.4^{a}	38.4^{a}
	SO_2	10.3^{a}	8.4^{a}	11.4^{a}	8.7^{a}	10.4^{a}	8.0^{a}	10.5^{a}	9.6^{a}
	MO_2	7.6^{a}	7.4^{a}	8.3^{a}	6.7^{a}	8.6^{a}	6.6^{a}	9.5^{a}	5.4^{a}
630 Dawn	pH	7.48^{a}	7.31^{a}	7.69^{a}	7.52^{a}	6.71^{a}	7.25^{a}	7.64^{a}	6.70^{a}
	TotALK	58^{a}	70^{a}	57^{a}	71^{a}	36^{a}	87^{a}	53^{a}	67^{a}
	CO_2	2.7^{a}	3.3^{a}	1.3^{a}	4.5^{a}	3.2^{a}	4.5^{a}	1.9^{a}	6.3^{a}
	HCO_3^-	35.6^{a}	42.7^{a}	43.4^{a}	52.2^{a}	22.0^{a}	53.0^{a}	41.4^{a}	40.8^{a}
	SO_2	8.9^{a}	9.1^{a}	11.1^{a}	7.7^{a}	9.3^{a}	8.5^{a}	7.4^{a}	6.8^{a}
	MO_2	5.9^{a}	7.6^{a}	7.5^{a}	5.3^{a}	7.3^{a}	6.1^{a}	6.3^{a}	5.3^{a}

[a] Mean values in rows followed by the smae letter are not significantly different ($P<0.05$)
pH = hydrogen ion x 10^{-pH} g-ions/L
TotALK = total alkalinity (mg/L)
CO_2= carbon dioxide (mg/L)
HCO_3^- = bicarbonate (mg/L)
SO_2= surface oxygen
MO_2= mid-water oxygen (mg/L)

aquatic herbicide produces no differences in diel pH, soluble carbon and oxygen concentrations in homogenous ponds.

Water quality has long been recognized as a critical factor determining the productivity and species composition of aquatic systems (Moyle 1956; Armstrong and Schindler 1971). For this reason, it is important to understand which factors influence water quality and how these factors interact to establish water quality in a given system. Studies of aquatic macrophytes have demonstrated that these plants can significantly influence water quality by reducing growths of phytoplankton, influencing nutrient cycling, and modifying oxygen, pH, carbon dioxide, bicarbonate, and salinity cycles (Hutchinson 1975; Wetzel 1975; Shireman et al. 1982). The impact of aquatic macrophytes on any particular aquatic system, however, must be judged within the context of the whole ecosystem.

Limnological research has shown that aquatic systems are not static systems, but open systems having dynamic imports and exports of water, particulates, and dissolved substances. Within this context, the aquatic system and its catchment area are the basic ecosystem unit because terrestrial and aquatic portions of any watershed are intimately linked by gravitational movements of materials from land to water (Likens and Bormann 1974). Several studies of regional limnology have demonstrated that surface geology and physiography (edaphic factors) are major determinants of the mineral composition and trophic status of aquatic systems (Deevey 1940; Rawson 1951; Moyle 1956; Bachmann 1965; Jones 1977; Jones and Bachmann 1978; Canfield 1981). For example, Moyle (1956) demonstrated that lakes in northeast Minnesota have low concentrations of dissolved salts, phosphorus, and nitrogen and are generally oligotrophic. In this region, surface geology is dominated by igneous and metamorphic rocks that are relatively resistant to dissolution and erosion processes. In southwest Minnesota, mineral-rich glacial drift material dominates surface geology. Lakes in this region are generally rich in dissolved salts and nutrients and are eutrophic.

Although edpahic factors establish a regional potential for water chemistry in aquatic systems, differences in land use practices, lake morphometry, and hydrology can cause major differences among lakes within a region. Changes in land use resulting from either natural or anthropogenic activities can alter ion, particulate, and water losses from the watershed (Hasler 1947; Edmondson 1972; Dillon and Rigler 1975; Jones et al. 1976; Likens et al. 1977). Schindler (1981) showed that lakes having large watershed to lake volume ratios generally have higher concentrations of nutrients and other dissolved salts than lakes having low watershed to lake volume ratios. This results because lakes with low watershed to lake volume ratios have more water to dilute inputs of salts and nutrients. In systems having active outlets and large inputs of water, hydraulic flushing can remove materials from an aquatic system. However, if evaporation exceeds precipitation, nutrients and salts can accumulate in the system. Vollenweider (1969) summarized the interaction of these factors in his general nutrient loading model:

$$TP = \frac{L}{z\ (\sigma + p)}$$

where TP = concentration of total phosphorus in the lake water, mg/m^3, L = annual phosphorus load from all sources per unit of lake surface area, mg/m^2/yr, Z = mean depth of the lake, m, G = phosphorus sedimentation coefficient, /yr and p = hydraulic flushing rate /yr.

Although the factors included in the general Vollenweider model can account for most of the variance in nutrient concentrations among lakes (Bachmann 1980; Canfield and Bachmann 1981), and most likely other water quality parameters, other factors including the biota of an aquatic system can modify water quality (Shapiro 1979). For example, Smith (1982) and Canfield (1983) have demonstrated that phosphorus and nitrogen concentrations are important determinants of chlorophyll *a* concentrations in Florida lakes, accounting for a little over 80% of the sample variance. Canfield et al. (1983) recently showed that incorporation of a term for aquatic macrophyte abundance, expressed as a percentage of the lake's total volume infested with macrophytes, could significantly improve the nutrient-chlorophyll relationship. The best fit regression equation was:

$$\mathrm{LCG(Chla} = 1.02\mathrm{LOGTN} + 0.28\mathrm{LOGTP} - .005\mathrm{VEG} - 2.08 \quad (2)$$

where Chla = chlorophyll *a* mg/m^3 TN = total nitrogen, mg/m^3 TP = total phosphorus, mg/m^3, and VEG = % of lake total volume infested with macrophytes.

Although this model was designed to predict average lake chlorophyll concentrations, the model predicted seasonal changes in chlorophyll levels in Lake Pearl (Figure 38). The model does, however, fail to predict the high chlorophyll levels that occur following herbicide or grass carp treatments, but the predicted average value (9 mg/m^3) was not significantly different from the measured average value (12 mg/m^3). Though this suggests, similar to the findings of Hasler and Jones (1949) and others, that macrophytes inhibit phytoplankton, macrophytes only have this effect when their abundance is high. Canfield et al. (1983) found that at least 40% of the lake total volume had to be infested with macrophytes before a significant reduction in chlorophyll levels occurred. At these levels, macrophytes constitute a problem and the public usually demands some sort of control. At lower levels of abundance, macrophytes may reduce planktonic chlorophyll levels within the macrophyte beds, but will have little effect on overall lake chlorophyll values.

Our study like many other studies demonstrates that in some lakes under certain conditions macrophytes can have an effect on water quality. However, as shown in the case of Lake Pearl, major changes in overall lake water quality only occur when macrophyte abundance is high and generally above levels acceptable to user groups. The Lake Pearl study also demonstrates that changes in water quality should be expected when macrophyte abundance is significantly reduced. In general, the changes in water quality will be short term and the lake will return to its potential based on nutrient loading rates, lake mean depth, hydraulic flushing, and sedimentation. The Orange Lake and Welaka Pond studies, however, demonstrate that even when macrophytes are high, no effect on water quality may be shown. This occurs because other factors such as changes in hydrology can influence water quality more than the macrophytes. The overall effects on long-term water quality occur only when macrophyte abundance is extremely high and at nuisance levels. This suggests that macrophytes can be removed from an aquatic system without detrimental effects on water quality.

Phytoplankton

Lake Pearl

A total of 63 phytoplankton genera were collected from Lake Pearl during this study (Table 27). For analysis, algae were grouped together into six major categories: Chlorophyta (green algae), Eugleophyta (euglenoids), Pyrrhophyta (dinoflagellates), Cryptophyta (cryptomonads), Chrysophyta (yellow greens), and Cyanophyta (bluegreens).

Fluctuations in algal abundance were related to season and herbicide application and finally to erradication of hydrilla (Figure 70). From February 1979 through November 1979, bluegreen algae were dominant and during May 1979, the number of bluegreen algae were significantly greater than all other dates except August 1981. The bluegreen peak during May 1979 was due to a bloom of *Synechocystis* The peak during July 1981, however, was due to a bloom of the filamentous alga (*Lyngbya*). After November 1979, green algae became the dominant group. All groups including green algae were not abundant from November 1979 through May 1981 and only once during this period (August 1980) did a noticeable peak in green algae abundance occur (Figure 70). This peak was comprised primarily of *Scenedesmus* and *Chlamydomonas*. This minor bloom was probably caused by nutrient release due to an application of hydout the month before. Similar results were recorded from the Welaka ponds after herbicide application.

The abundance of green algae increased considerably after June 1981 when the percent hydrilla volume in Lake Pearl began to decline. The greatest abundance of green algae occurred during March 1982 when the numbers were significantly greater than all months except August 1981. The bloom during March was due primarily to the genus *Sphaerocystis*, whereas the blooms during August and December 1981, were due to the abundance of an unidentified green alga. By the end of the study, after hydrilla eradication, the phytoplankton of Lake Pearl consisted almost entirely of green algae (Figure 70).

The number of genera collected reflected similar trends as did total numbers. Greater numbers of genera were collected from February through September 1979 (4 to 10 genera per collection) and from April 1981 through May 1982 (8 - 19 genera per collection). During the mid study months (October 1979 through March 1981) the number of genera per collection ranged from 2 to 7 genera, excluding the August 1980 bloom, when 17 genera were collected. The greatest variety of algae was associated with collections that

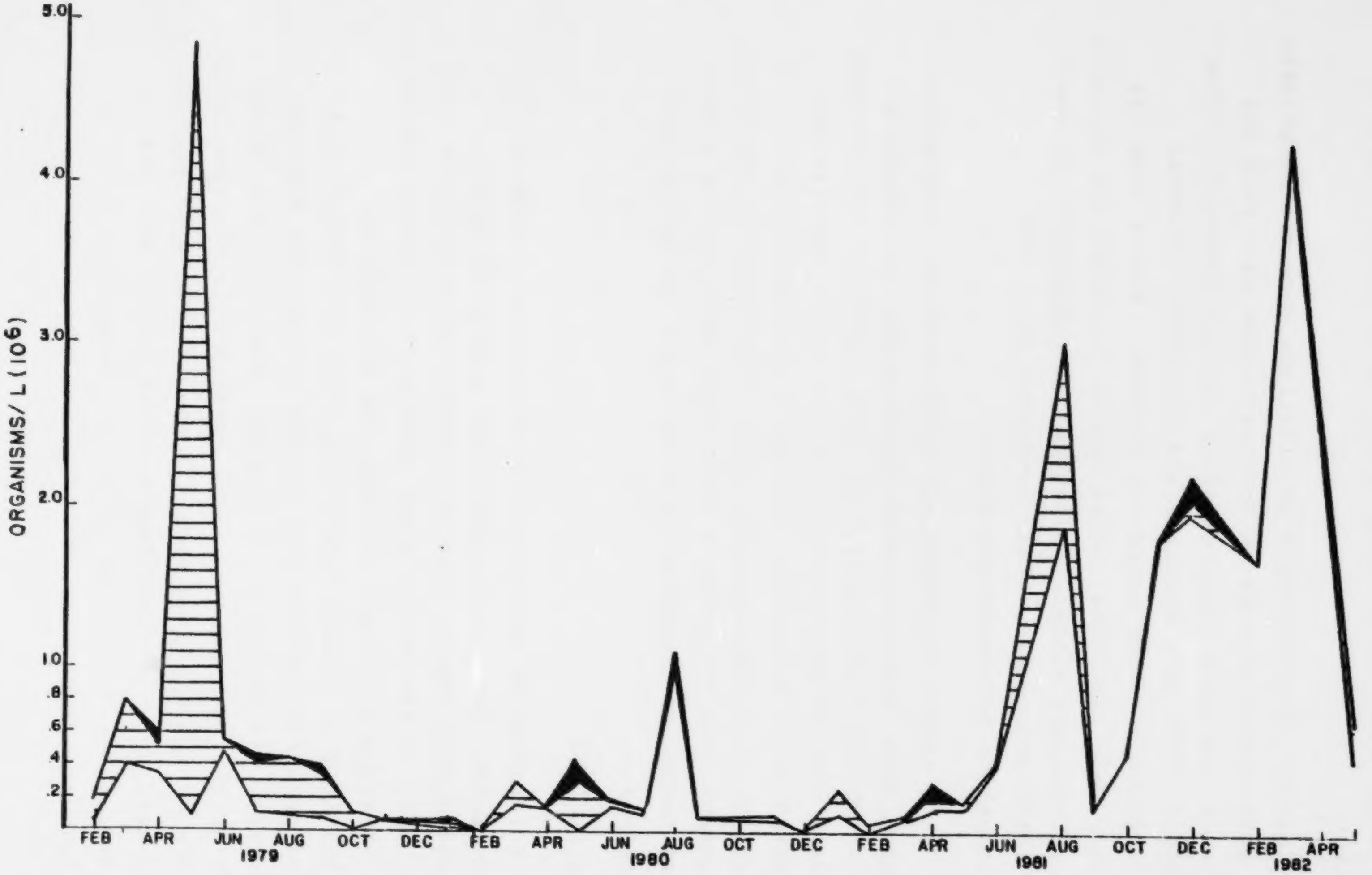


Figure 70. Mean number of phytoplankton according to algae groupings (green algae ☐ , bluegreen algae ▤ yellow green algae ■ and other algae ▥) for Lake Pearl, Florida.

contained primarily green algae. It was noted, however, that during bloom periods one or two genera often became dominant.

Seasonal phytoplankton oscillations were characteristic with high levels from March through August each year and declining abundance from September through February. After September 1981, when hydrilla was declining, seasonal oscillations in algae abundance changed. Rather than the expected fall reduction, algal levels increased and remained high through the winter. Although not consistent, it seems that after vegetation volume decreased below 50% phytoplankton abundance increased.

Seven genera (*Scenedesmus*, *Chlamydomonas*, *Anacystis*, *Synechocystis*, *Ankistrodesmus*, *Staraustrum* *and* *Cosmarium*) were collected most frequently. *Synechocystis* was the most abundant species collected in any one month, but was not collected after May 1981. Another bluegreen algae, *Anacystis*, although collected frequently early in the study was absent from collections after June 1981. Green algae genera tended to dominate after herbicide and grass carp treatments.

Orange Lake

A total of 89 phytoplankton genera were collected from Orange Lake. The variety and total number of algae collected from Orange Lake was greater than collected from Lake Pearl or the Welaka ponds (Table 27). Phytoplankton were arranged by groups as described previously. Fluctuations in Orange Lake algae abundance seemed to be caused primarily by seasonal change rather than hydrilla abundance. It is unlikely, however, that hydrilla became dense enough to influence algal abundance in the open water portion of the lake, as hydrilla ranged from only 16.5 to 21.9% coverage. In Lake Pearl, algal levels were not influenced until hydrilla volume declined below 50%; coverage remained above 80%.

Table 27 . Phytoplankton collected from lakes Orange and Pearl and the Welaka ponds. Genera collected only from one lake indicated by parentheses.

Taxon	Genera
Chlorophyta (Green)	
Volvocales	Chlamydomonas
	Pondorina
	Volvox
	Eudorina (Pearl)
Testrasporales	Asterococcus (Orange)
	Gloeocystis
	Botryococcus
Chlorococcales	Actinastrum (Orange)
	Ankistrodesmus
	Chlorella
	Chlorococcus (Orange)
	Coelostrum
	Crucigenia
	Desmotractum
	Dictyosphaerium (Orange)
	Dimonohococcus (Orange)
	Golenkinia
	Kirchneriella
	Lagerheimia
	Micractinium
	Oocystis
	Pachycladon (Orange)
	Palmella
	Pediastrum
	Scenedesmus
	Schroederia
	Selenastrum
	Sphaerocystis (Orange)
	Tetraedron (Orange)
	Treubaria (Orange)
Ulotrichales	Microspora
	Ulotrix
Chaetophorales	Protococcus (Orange)
Oedogoniales	Oedogonium
Zygnemotales	Arthrodesmus
	Closterium
	Cosmarium
	Desmidium
	Microsterias
	Phymatodocis
	Staurastrum

Table 27. Continued.

Taxon	Genera
Siphonocladales	Rhizoclonium (Pearl)
Euglenophyta	
Euglenales	Euglena Phacus Trachelomonas
Pyrrhophyta	
Dinokontae	Ceratium Peridinium
Cryptophyta	Cryptomonas Rhodomonas
Chrysophyta	
Xanthophycene	
Rhizochloridales	Rhizachloridoceae
Mischoccales	Centritractus (Orange) Ophiacytium
Tribonematales	Tribonema (Orange)
Chrysophyceae	
Ochramonodaceae	Dinobryon Mollomonas Uroglenopsis (Pearl)
Bacillariophyceae	
Centrales	Attheya (Orange) Cascinodiscus Cyclotella (Orange) Melosira (Orange) Rhizosolenia (Orange)
Pennales	Achnantes (Orange) Amphipleura Asterianella (Orange) Centronella Cocconeis (Orange) Fragilaria (Orange) Frustulia Gomphonema (Orange) Gyrosigma Novicula Nitschia (Orange) Opephora Rhapaladia Stauroneis (Orange) Tabellaria (Orange) Diatoma (Orange) Opehora

Table 27. Continued.

Taxon	Genera
Cyanophyta (Blue green)	
Chroococcales	Anacystis
	Coelospherium
	Dactylococcopsis
	Merismopedia
	Synechosysis
Oscillatoriales	Lyngbya
	Oscillatoria
	Spirulina (Orange)
Nostocales	Anabaena (Orange)
	Anabaenopsis
	Aphanizomenon
	Gloeotrichia (Orange)
	Cylindrospermum (Orange)

Orange Lake phytoplankton was dominated by bluegreen algae except during March 1979, when a bloom of the green alga *Coelastrum* occurred. After this bloom, green algae levels ranged from approximately 0.5 to 2.5 x 10^6 organisms per liter (Figure 71). Generally, the dominant green algae collected during the study were *Ankistrodesmus*, *Scenedesmus*, and *Staurastrum*. Although green algae abundance fluctuated throughout the study, there seemed to be a trend toward lowest numbers in the winter months (Figure 71).

The dominant bluegreen genera were *Lyngbya*, *Anabaena*, *Anacystis*, *Spirulina* and *Oscillatoria*. *Lyngbya* was the dominant genera occurring in the major peaks after June 1980. The dominant yellow green genera during the October 1980 peak was *Melosira*. *Achnanthes* was dominant during the October 1981 peak (Figure 71). In addition, the yellowgreen algae *Amphipleura*, *Frustula* and *Gomphonema* were represented throughout the year, but were never abundant.

Welaka Ponds

Examination of vegetation levels (Figures 16-22) indicated that intended macrophyte control was not approached until January 1981 in most ponds. Phytoplankton populations underwent their greatest oscillations during 1979 and 1980, before ponds reached equilibrium with respect to algal dominance and treatment impact (Tables 28,29 and 30). All ponds were dominated by green algae, with bluegreen and yellow-green algae occurring in low densities except during the two initial sample periods when a bluegreen bloom occurred in all treatment ponds. Primary genera during this bloom were *Anabaena*, *Synechocystis*, and *Anacystis*. Bluegreen algae were not collected in significant quantitities in any of the treatments in 1981 and 1982, except in the 100% herbicide control ponds. In November 1981, a temporary *Lyngbya* bloom occurred after summer herbicide treatments were initiated.

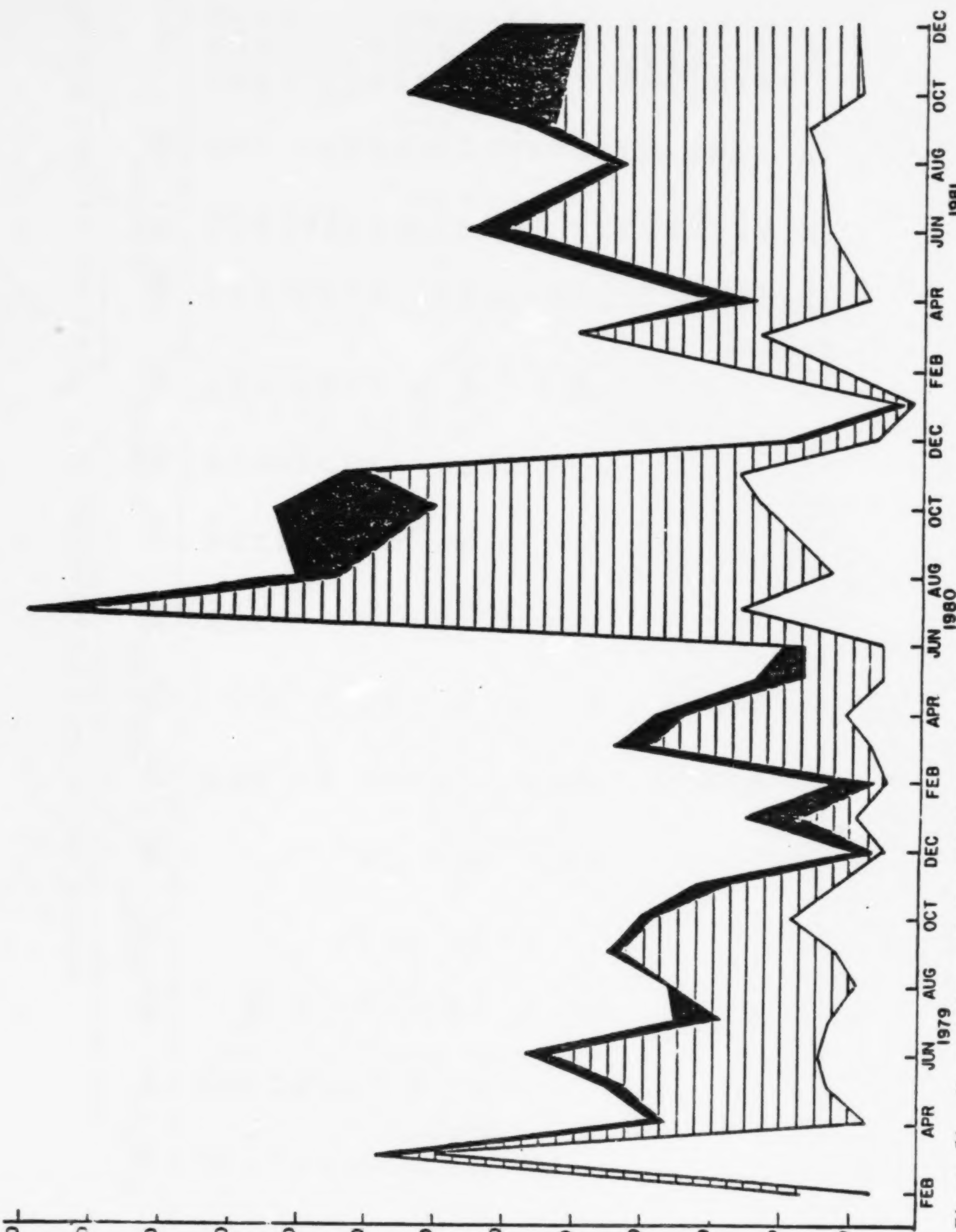


Figure 71. Mean numbers of phytoplankton according to major groupings (green algae □, bluegreen ▤ yellow green algae ■ and others ▥) for Orange Lake, Florida.

Table 28. Number per liter (x 10^6) of phytoplankton in the grass carp ponds in Welaka.

Date	Chlorophyta			Cyanophyta			Chrysophyta			Others			Totals		
	30%	60%	100%	30%	60%	100%	30%	60%	100%	30%	60%	100%	30%	60%	100%
5/21/79	.20	.55	.27	.55	.38	5.55	.06		.19				.81	.93	6.01
6/26/79	.65	.42	.36	2.66	.12	.10	.25	.04	.06				3.56	.58	.52
7/24/79	1.20	.94	.65	.02	.02	.19	.19	.21	.19			.02	1.59	1.17	1.05
8/22/79		.40	.16	.13	.39	.09		.04					.13	.83	.25
9/20/79	.64	.34	.40	.06	.04	.06						.02	.70	.38	.50
10/21/79	.19	.68	.60	.02	.15	.13		.15	.02				.21	.98	.65
11/29/79	.44	.35	.50	.02	.04						.02		.46	.41	.50
1/20/80	.94	.31	.40	.09	.04		.17	.02	.04	.06	.08	.04	1.22	.45	.48
2/21/80	1.24	.41	.38			.02		.04	.06	.13	.08	.02	1.37	.53	.53
4/21/80	2.26	2.12	.27	.06			.13				.02	.04	2.45	2.14	.31
5/20/80	2.16	3.61	1.69		.11		.09		.11	.02		.02	2.27	3.72	1.82
7/20/80	.42	6.05	.12	.06	.25	.09	.15	.06		.02	.02	.09	.65	6.38	.30
9/20/80	.51	1.17	.16		.04		.04			.04	.02	.02	.59	1.23	.18
11/20/80	.59	1.52	.57		.04		.04				.08		.63	1.60	.57
1/20/81	.04	.03					.02	.01	.04		.02	.09	.06	.06	.13
2/20/81	.06	.13	.10				.29	.09	.11	.02			.37	.23	.21
3/20/81	.21	.36	.10	.04			.04	.02	.04	.06		.04			
4/20/81	.45	.16	.45				.04	.84	.32	.54	.01	.34			
6/20/81	.06	.20	.19												
7/20/81	.08	.30	.27												
10/20/81		.05	.17				.02	.05	.04						
12/20/81	.10	.06	.05					.02	.12			.02			
1/20/82	.08	.06	.03					.06	.06			.01			
2/20/82	.05	.06	.08				.03	.02	.02						
3/20/82		.06	.04				.02	.04	.04						
Overall mean	.50	.81	.32	.15	.07	.25	.06	.07	.06	.04	.01	.03			

Table 29. Number per liter (x 10^6) of phytoplankton in the herbicide ponds in Welaka.

Date	Chlorophyta			Cyanophyta			Chrysophyta			Others			Totals		
	30%	60%	100%	30%	60%	100%	30%	60%	100%	30%	60%	100%	30%	60%	100%
5/21/79	.16	3.27	.16	3.14	6.21	.40	.06		.15				3.36	9.48	.55
6/26/79	.52	.42	.44	.27	.08	6.75	.06	.06	.10				.85	.56	7.29
7/24/79	.68	.20	.21	.11	.06	.04	.15	.23	.30		.02		.94	.53	.55
8/22/79	.83	.43	.47	.44	.13	.17	.02	.02				.15	1.29	.58	.79
9/20/79	1.90	1.40	1.47	.04	.15	.12		.02	.02	.04			2.16	1.57	1.61
10/21/79	.49	.80	.29	.06	.08	.06	.04	.19	.02	.04	.02	.02	.63	1.09	.39
11/20/79	.38	.74	.22					.02	.02				.38	.76	.24
1/20/80	.34	.76	.70	.09		.04	.02			.21	.26	.32	.66	1.01	1.06
2/21/80	.79	1.09	.17		.06		.02	.11		.13	.11		.95	1.38	.17
4/21/80	.82	1.21	2.27			.02		.06		.34	.02		1.16	1.29	2.29
5/20/80	.91	3.58	1.70	.19	.18	.06	.09	.19	.04	.02		.13	1.21	3.97	1.93
7/20/80	.17	2.38	4.17	.06	.62	.08				.02			.25	3.00	4.25
9/20/80	.10	6.49	1.11		.04	.02	.04	.02			.45	.04	.14	7.01	1.17
11/20/80	.10	12.93	1.06			.06	.02	.04	.04				.12	12.97	1.16
1/20/81	.02	.04	1.26			.04	.02	.06	.16	.08	.04	.13	.12	.14	1.59
2/20/81	.02	.10	1.45		.02		.02		.13	.10	.04	.02	.14	.16	1.62
3/20/81	.33	.63	5.82	.08		.02	.08	.28		.19	.26	1.09	.67	1.17	6.93
4/20/81	.32	7.16	.91	.02			.04				.02	.65	.38	7.18	1.56
6/20/81	.21	.12	.06							.04			.25	.12	.06
7/20/81	.10	.17	.06								.02		.10	.19	.06
10/20/81	.22	.17	5.29			7.59	.02			.06		.13	.30	.17	13.01
12/20/81	.06	.06	3.27				.06	.03	.02	.02	.04	.02	.14	.13	3.31
1/20/82	.04	.03	.47				.08	.04	.08	.02	.02		.14	.09	.55
2/20/82	.06	.06	.08				.04		.04				.10	.06	.12
3/20/82	.08	.04	.04				.02		.04				.10	.04	.08
Overall mean	.39	1.77	1.33	.18	.31	.62	.04	.06	.05	.05	.05	.11			

Table 30. Number per liter (x 10^6) of phytoplankton in the fertilization and the 100% vegetated ponds in Welaka.

Date	Chlorophyta		Cyanophyta		Chrysophyta		Others		Totals	
	Fert.	100% Veg,	Fert.	100% Veg.	Fert.	100% Veg.	Fert.	100% Veg.	Fert.	100% Veg.
5/21/79	3.20	.08	4.10	8.87	.04		.02		7.36	8.95
6/26/79	.41	.31	.15	.15	.06				.62	.46
7/24/79	.35	.81	.04	.17	.10	.21			.49	1.19
8/22/79	.21	.65	.17	.60		.02	.02	.02	.40	1.29
9/20/79	.30	.40	.19	.53			.06		.55	.93
10/21/79	.75	.38	.13	.08	.09				.97	.46
11/20/79	.14	.63		.11	.06				.20	.74
1/20/80	.29	.47			.32	.06	.08	.08	.69	.61
2/21/80	.27	.52		.13		.02		.06	.27	.73
4/21/80	.38	.49	.11	.02	.04	.17	.02	.04	.55	.72
5/20/80	12.39	2.79	5.83	.30		.21	.04	.15	18.26	3.45
7/20/80	3.65	5.28	6.12	.88		.04		.08	9.77	6.64
9/20/80	.28	2.51	.02	.02		.02		.06	.32	2.61
11/20/80	.46	.47	.02	.04	.10		.02		.60	.51
1/20/81		.02	.02		.17	.02	.06		.25	.04
2/20/81	.06	.18	.06		.09	.19			.21	.37
3/20/81	.39	.29	.04	.02	.02	.02	.02	.06	.47	.39
4/20/81	.06	.31			.13			.07	.19	.38
6/20/81	.06	.23		.06					.06	.29
7/20/81	.10	.19		.06	.02				.12	.25
10/20/81	.18	.04	.02		.02				.22	.04
12/20/81	.03				.12	.02			.15	.02
1/20/82	.05				.03	.02	.04		.12	.02
2/20/82	.07	.04			.03				.10	.04
3/20/82	.10	.04			.04				.14	.04
Overall mean	.97	.69	.68	.48	.06	.05	.02	.03		

Examination of 1981 and 1982 phytoplankton data when vegetation control levels were reached, indicated significant differences existed with respect to method of treatment (Tables 28,29 and 30). Maximal cells/liter occurred in the 60% and 100% herbicide control ponds, (8.6 and 2.63 x 10^6) respectively. In the grass carp ponds, fertilization ponds and the 100% vegetated ponds significantly different algal standing crops did not occur. The relatively low number of cells per liter in the fertilization ponds (1.8 x 10^5) was due to the continuous presence of aquatic macrophytes. Although macrophytes were mechanically harvested prior to almost all fertilizer applications, phytoplankton densities could not be maintained high enough to physically shade the remaining aquatic vegetation. Total phytoplankton standing crops were not significantly different in the grass carp treatment ponds regardless of the amount of vegetation removed. These results suggest that nutrient release into the water column from the grass carp fecal material may be slower than when herbicides are used. The relatively slow removal of macrophytes by grass carp prevents abrupt influxes of nutrients and converts nutrients in the plants into fish protein (Bailey 1972, Miley et al. 1979). Several authors (Opuszynski 1972, 1979; Provine 1975; Guillory 1979; von Zon 1979) report that herbicides kill macrophytes quickly causing release of nutrients directly in the water for future vegetative growth. In experimental pools, Hestand and Carter (1978) observed that phytoplankton blooms occurred with the use of chemicals, but not with grass carp. In the Welaka 60 and 100% herbicide ponds, large blooms occurred after every herbicide treatment due to the rapid release of nutrients from decaying macrophytes. The major blooms occurring in 1981 and 1982 in the 100% herbicide ponds were caused by the bluegreen alga Lyngbya and the green alga Ankistrodesmus. The 1981 phytoplankton bloom in the 60% herbicide control ponds was due to a large increase in Chlamydomonas. The same trends did not occur in the 30%

herbicide control ponds, indicating that vegetation management levels <30% do not cause significant changes in phytoplankton densities.

The fertilization ponds contained the most diverse phytoplankton populations, as 55 genera were identified. The 30% grass carp ponds contained only four genera (Table 31), but no trends were evident that would suggest total number of phytoplankton genera or species were dependent on vegetation level. Dominant species did, however, vary with treatment methods and vegetation levels. Chlamydomonas was the only genera dominant in all of the Welaka ponds. The green alga, Scenedesmus, was important in all treatment ponds except in the 60% grass carp ponds. Control ponds (100% vegetation) contained no dominant species during the study. Individual genera were dominant only during two or three sample periods; then abundance shifted to another genera. Within the 100% vegetated ponds, Chlamydomonas was the only genera that occurred in appreciable numbers in more than two collections.

Fertilized ponds were dominated by three green algae, Ankistrodesmus, Chlamydomonas and Scenedesmus (Table 32). The cryptomonad, Rhodomonas, was the only other important genus. During the last two study years, numerous genera of dinoflagellates, cryptomonads and yellow green algae caused single simple peaks, which indicated a shift away from total dominance by green and bluegreen algae that occurred during the first two study years.

The grass carp treatment ponds underwent a peak in algal abundance in Spring 1981. Peridinium and Oocystis were the primary genera collected from the 30% vegetation control ponds. Neither of these genera were numerous after the bloom dissipated. The Spring 1981 phytoplankton bloom in the 60% grass carp control ponds was due almost entirely to the yellow green algae, Dinobryon. This genus was dominant only in the 60% and 100% vegetation control ponds where grass carp were utilized and was present in most of

Table 31. Genera of phytoplankton collected within the Welaka ponds.

Genera	30%	60%	100%	30%	60%	100%	Fertilization	100% Vegetation
Chlorophyta								
Scenedesmus	+	+	+	+	+	+	+	+
Pediastrum		+	+		+	+	+	+
Selenastrum		+	+	+		+	+	+
Microsterias					+	+		+
Desmidium	+	+	+	+	+	+	+	+
Closterium		+	+	+	+	+	+	+
Tetraedron	+	+	+	+	+	+	+	+
Sphaerocystis	+	+	+	+	+	+	+	+
Schroederia				+	+			
Chlamydomonas	+	+	+	+		+	+	+
Volvox		+	+	+	+	+	+	+
Crucigenia	+	+	+	+	+	+	+	+
Oocystis	+	+	+	+	+	+	+	+
Desmotractum		+	+		+	+	+	+
Pandorina			+				+	+
Palmella						+		+
Golenkinia	+	+	+	+	+	+	+	+
Botryococcus	+	+	+		+	+	+	
Gloeocystis	+	+	+	+	+	+	+	+
Arthrodesmus	+	+	+	+	+	+	+	+
Actinastrum		+	+	+		+		+
Ulotrix	+							+
Microspora	+		+	+			+	+
Kirchneriella		+	+		+	+	+	+
Dimorphococcus		+						
Asterococcus								
Treubaria		+					+	
Lagerheimia				+			+	
Chlorella		+				+		
Protococcus		+	+				+	
Dictyosphaerium	+						+	
Micractinium			+					
Coelostrum	+	+	+	+	+	+	+	+
Cosmarium	+	+	+	+	+	+	+	+
Staurastrum	+	+	+	+	+	+	+	+
Eustrum	+	+	+	+	+	+	+	+
Ankistrodesmus	+	+	+	+	+	+	+	+
Oedogonium	+	+	+			+		+
Dactylococcus			+					
Euglenophyta								
Euglena	+	+		+			+	+
Phacus	+	+	+	+	+	+	+	+
Trachelomonas	+	+	+	+	+	+	+	+
Pyrrhophyta								
Peridinium	+	+	+	+	+	+	+	+
Cryptophyta								
Cryptomonas			+	+	+		+	
Rhodomonas	+	+	+	+	+	+	+	+

Table 31. Continued.

Genera	30%	60%	100%	30%	60%	100%	Fertilization	100% Vegetation
Chrysophyta								
Chrysostomaceae		+	+	+	+	+	+	+
Rhizachloridoceae		+		+	+			
Centritractus		+		+	+		+	+
Dinobryon	+	+	+	+	+	+	+	+
Mallomonas	+	+	+	+	+	+	+	+
Uroglenopsis								
Cyclotella						+		
Melosira				+			+	
Asterianella				+				
Centronella			+				+	
Fragiliaria					+		+	
Frustulia	+	+	+	+	+	+	+	+
Coscinodiscus	+	+	+	+	+	+		
Amphipleura	+	+	+			+	+	+
Opephora			+					+
Rhepaladia	+		+	+		+		
Novicula	+	+	+	+	+	+	+	+
Gyrosigma						+		
Tabellaria								+
Stauroneis				+			+	
Diatoma		+			+		+	
Cyanophyta								
Anacystis	+	+	+	+	+	+	+	+
Coelospherium		+		+	+			
Dactylococcopsis	+	+	+	+	+	+	+	+
Merismopedia	+	+	+	+		+		+
Synechosysis	+	+	+	+	+	+	+	+
Lyngbya				+		+	+	+
Oscillatoria	+	+		+	+	+	+	+
Spirulina							+	
Anabaena	+	+	+	+	+	+	+	+
Aphanizomenon	+	+		+	+	+	+	+

Table 32 . Dominant genera of phytoplankton by treatment in the Welaka ponds from January 1981 to March 1982.

	Treatment							
	Grass Carp			Herbicide			100%	
Genera	30%	60%	100%	30%	60%	100%	Vegetation	Fertilization
Chlorophyta						+	+	
Ankistrodesmus	+	+	+	+	+	+	+	+
Closterium						+		
Chlamydomonas	+	+	+	+	+	+	+	+
Scenedesmus	+		+	+	+	+	+	+
Selenastrum							+	
Tetraedron						+		
Pyrrhophyta								
Peridinium				+	+	+		
Cryptophyta								
Rhodomonas	+	+	+	+			+	+
Crysophyta								
Dinobryon		+	+					
Cyanophyta								
Anacystis							+	
Mean number of cells/liter x 10^6 (all organisms)	.20	.24	.25	.22	.86	2.63	.17	.18

the collections. The 100% vegetation control ponds with grass carp also had a large spring peak due to a temporary increase in abundance of *Dinobryon*, *Peridinium* and *Scenedesmus*. The remainder of the collection periods were dominated by *Chlamydomonas* and *Rhodomonas*. In all grass carp ponds, *Scenedesmus* was a dominant organism in the 30 and 100% grass carp macrophyte removal ponds, but was not dominant in the 60% vegetation-free ponds.

The dinoflagellate, *Peridinium*, was one of the dominant phytoplankters in all the ponds that received herbicide treatments. In all other treatments, it was important only during monthly blooms. Within the 30% herbicide ponds, *Chlamydomonas* and *Scenedesmus*, the dinoflagellate, *Peridinium*, and the cryptomonad, *Rhodomonas*, were dominant.

Maximal plankton densities occurred in the 100% herbicide ponds, with repetitive blooms occurring every spring and fall. The bloom in the 100% herbicide ponds in Spring 1981 was due to *Tetraedron*, *Closterium* and *Peridinium*. The 1981 fall bloom was caused by *Lyngbya* and *Ankistrodesmus*.

Data collected from Lake Pearl and the Welaka ponds suggest that a relationship exists between the level of aquatic macrophytes and phytoplankton. In Lake Pearl, algal levels increased when vegetation volume was reduced below 50%, whereas in Orange Lake a relationship was not noted because vegetation did not reach critical levels.

In the Welaka pond studies, significant differences occurred in respect to treatment methods. Maximum number of phytoplankton per liter occurred in the 60 and 100% herbicide control ponds, whereas differences were not apparent in the grass carp control ponds. In small enclosed systems, such as aquariums, plastic pools and similar non-flowing, small unnatural systems, herbicides and subsequent decay of aquatic vegetation leads to at least temporary increases in plant nutrients and algal populations (Hestand

and Carter 1978, Walker 1963). As stated previously, nutrients are released more slowly when grass carp are used and, of major importance is the nonsignificant relationship between phytoplankton and macrophytes at low control levels (70-100%) regardless of control method.

The relationship between algal levels and macrophyte density has been debated and discussed. Numerous investigators suggest, as we do, that an inverse relationship exists between the development of phytoplankton populations and aquatic macrophyte abundance (Kofcid 1903; Hasler and Jones 1949; Goulder 1969; Canfield et al. 1983). This relationship may exist for several reasons including shading (Hasler and Jones 1949; Goulder 1969), nutrient uptake by macrophytes or associated epiphyton (Weibe 1934; Bennett 1942), inhibitory substances (Fitzgerald 1969), reduction in nutrient cycling through the prevention of wind resuspension of bottom sediments, and reduction in water turbulence by macrophytes that enhances the sedimentation of phytoplankton.

Changes in algal abundance and composition, however, were reported after macrophyte reduction by Edwards (1975), EPA (1979), and Crisman and Kooijman (1981). The general opinion is that as eutrophication occurs, which can be caused by macrophyte removal, the number of bluegreen algae increases. Based on a survey of 165 lakes, Canfield and Hodgson (unpublished data) found that no relationship existed between the dominance of any specific algal group and the trophic status of lakes. This suggests that the often observed dominance of bluegreen algae in eutrophic northern lakes does not necessarily occur in warmer southern lakes. Crisman and Koojiman (1981) found that the phytoplankton of Lake Conway, Florida, changed from a green algae dominated system to a bluegreen dominated system after grass carp stocking. The results obtained from Lake Pearl, however, show a reverse trend as the abundance of green algae increased after vegetation control.

Periphyton

Lake Pearl

Changes in the periphyton community following herbicide treatments in Summer 1980 are shown in Figures 72, 73 and 74. As shown by changes in chlorophyll a, peaks in periphyton biomass followed the first and second herbicide treatments (Figure 72). These treatments effectively controlled hydrilla. The third treatment had little effect on hydrilla; but, an increase in periphyton chlorophyll a was observed. The fourth treatment also controlled hydrilla, but increases in periphyton were not significant.

Biovolumes (Figure 73) and cell numbers (Figure 74) are included here for completeness. The variability of the biovolume data makes it of dubious value for interpreting subtle changes due to treatment. Cell numbers are misleading because of great differences in the size of the cells counted. Biomass in March through May consisted primarily of large-celled filamentous green algae such as *Oedogonium* spp., *Mougeotia* spp. and *Spirogyra* spp. Later pulses in biomass consisted of populations of small forms, such as the pennate diatom, *Achnanthes linearis*, small blue-green filaments of *Lyngbya* sp. and green palmelloid forms including *Chlamydomonas* spp. and *Askenasyella* sp.

These results show that when hydrilla is controlled by herbicides, a periphyton bloom occurs. Treating one end of a lake with herbicides changes many things which may affect algal growth: (1) nutrient content, through breakdown of the herbicide and the macrophytes, (2) bacterial populations, (3) circulation patterns within the lake, and (4) local fish behavior. This empirical result, however, gives little indication of the cause of the periphyton bloom. In this experiment, herbicide treatments were not sufficiently separated in time to allow experimental values to return to control levels between treatments. Our data are not yet detailed enough to assess the effect of

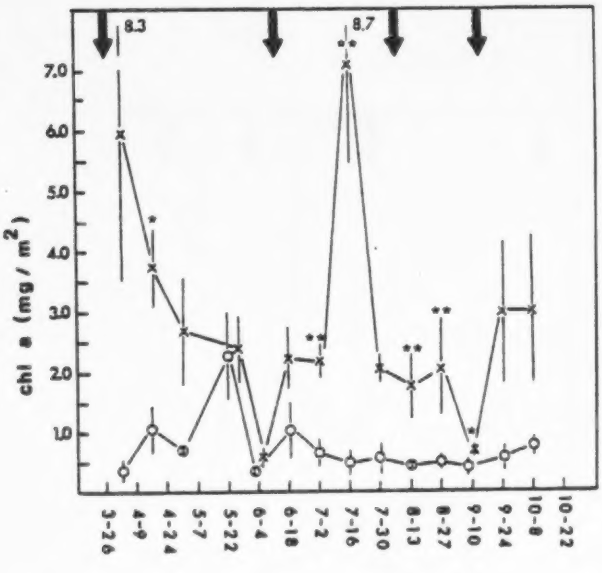


Figure 72. Chlorophyll a (mg/m^2) ± standard error, from glass slides immersed in Lake Pearl. (X = experimental, o = countrol, arrows indicate dates of herbicide treatments, *= experimental values significantly different from control values at the .05 level, **= different at the .01 level).

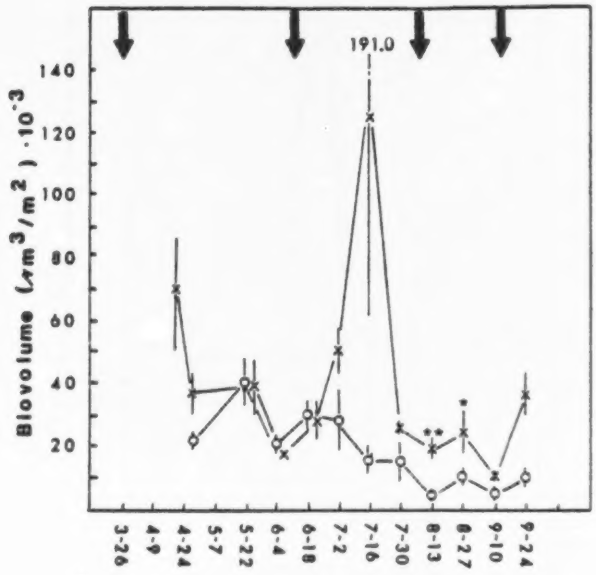


Figure 73. Biovolume (m^3/m^2) estimates ± standard error, derived from cell counts and measurements on glass slides immersed in Lake Pearl. (Data presented as in Figure 1).

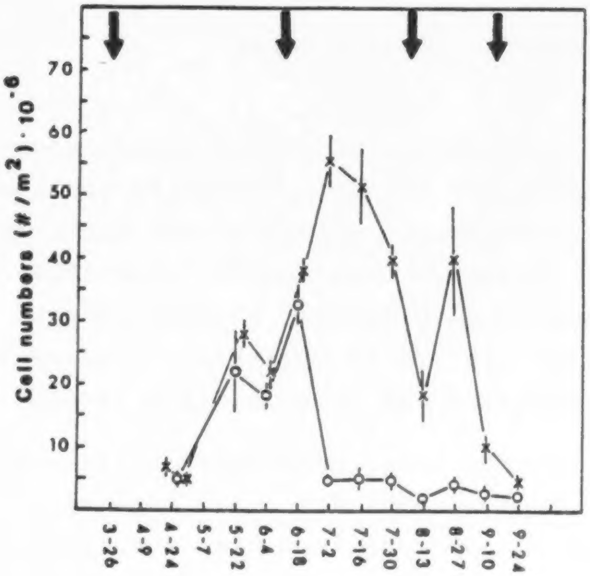


Figure 74. Cell numbers ± standard error, from cell counts on glass slides immersed in Lake Pearl. (Data as presented in Figure 1).

herbicide treatment upon the primary producer communities as a whole. From our study and that of Hestand and Carter (1978), the algal components of the system increase when macrophytes are reduced by herbicide treatments. Follow-up experiments in small 3.1 m diameter pools confirm that increases in both phytoplanktonic and periphytic algal communities follow treatment with herbicides (Hodgson, unpublished data). It might be hypothesized, then, that the total biomass of all primary producers in the system is changing very little when one component (here, macrophytes) is removed.

Aquatic Invertebrates

Lake Pearl

In Lake Pearl, an analysis of variance was conducted on invertebrate data using two factors: herbicide treatments (treated stations vs nontreated stations) and time periods [the control period (1979) vs test period (1980-1982)]. This analysis was designed to examine whether changes in invertebrate abundance was due to vegetation treatment or represents natural fluctuations in population levels.

A total of 23 benthic macroinvertebrate taxons were collected from Lake Pearl (Table 33). All taxa were collected in similar proportions from both the treated and non treated lake area (Table 34). Midges (dipterans), annelids (oligchaeta) comprised approximately 90% of the total numbers of macroinvertebrates collected. Results from the analysis of variance indicates macroinvertebrate abundance, both collectively and individually, were not significantly influenced by the herbicide treatment.

Although statistical significance was not indicated, changes in abundance seemed to be related to season and vegetation abundance. Seasonal changes in abundance were suggested by maximum numbers collected during the winter months (Figure 75). Seasonal abundance was probably related to temperature rather than vegetation levels. There was,

Table 33. A checklist of zooplankton and benthic macroinvertebrates collected from Lake Pearl, Florida, October 1978-May 1982.

Taxon		Common Name
Zooplankton		
Arthropoda		
Crustacea		Water flea
Cladocera		
Sididae	*Sida crystallina*	
	Diaphanosoma brachyurum	
	Latonopsis occidentalis	
Daphnidiae	*Daphnia ambigua*	
	Simocephalus vetulus	
	Ceriodaphnia reticulata	
Chydoridae	*Chydorus sphaericus*	
	C. hybridus	
	C. Piger	
	C. barroisi	
	Alona guttata	
	A. barbulata	
	A. monacantha	
	Kurzia latissma	
	Camptocercus rectirostris	
	Dunhevedia crassa	
	Pleuroxus denticularis	
	P. hastatus	
	Eurycercus lamellatus	
	Ilyocryptus spinifer	
	Graptoleberis testudinaria	
Bosminidae	*Eubosmina tubicen*	
Macrothricidiae	*Macrothrix rosea*	
	M. laticornis	
Copepoda		Copepods
Diaptomidae	*Diaptomus floridanus*	
Cyclopidae	*Cyclops* sp.	
Rotifera		Rotifers
Monogonata		
Ploima		
Brachionidae		
Brachioninae	*Brachionus havanaensis*	
	B. angularis	
	B. quadridentata	
	Keratella cochlearis	
	K. quadricornis	
	Kellicottia sp.	
	Playtias patulus	
	P. quadricornis	

Table 33.Continued.

Zooplankton (continued)		
Brachioninae	*Squatinella* sp.	
	Euchlanis sp.	
	Triplocalanus sp.	
	Diplocalanus sp.	
	Manfredium sp.	
	Mytilina sp.	
	Macrochaetus sp.	
	Scaridium sp.	
Lecaninae	*Lecane* sp.	
	Monostyla sp.	
Colurinae	*Lepadella* sp.	
Synchaetidae	*Polyarthra* sp.	
Asplanchnidae	*Asplanchna* sp.	
Tricorceridae	*Trichocerca* sp.	
Hexarthridae	*Hexarthra* sp.	
Notommatidae	*Cephalodella* sp.	
	Monommata sp.	
	Scaridium sp.	
Ploesomatidae	*Ploesoma* sp.	
Flosculariacea		
Testudinellidae	*Filina* sp.	
Conochilidae	*Conochilus* sp.	
Benthos		
Platyhelminthes		
Turbellari	Planariidae	Flatworms
Nematoda		Roundworms
Annelida		Aquatic earthworm
Oligochaeta		
Hirudinea		Leeches
Rhynchobdellida		
Glossiphoniidae	*Helobdella* sp.	
Arthropoda		
Crustacea		
Decapoda		
Palacinmonidae	*Palaemonetes kadiakensis*	Grass shrimp
Amphipoda		
Talitridae	*Hyalella azteca*	Scuds

Table 33. Continued

Benthos (continued)		
Insecta		
Ephemeroptera		
Baetidae	*Callibaetis* sp.	Mayflies
Odonata		
Libellulidae	*Erythemis* sp. *Paraponyx* sp.	Dragonflies
Coenagioniade	*Enallagma* sp.	Damselflies
Tricoptera		Caddisflies
Hydroptilidae	*Orthotrichia* sp. *Oxyethira* sp.	
Lepidoptera		Aquatic caterpillar
Leptoceridae	*Leptocercus* sp.	
Diptera		
Chaoboridae	*Chaoborus* sp.	Phantom midges
Chironomidae		Midges
Ceratopogonidae		Biting midges
Mollusca		
Gastropoda		
Pulmonata		
Ancylidae	*Ferissia* sp.	Limpets
Planorbidae	*Gyraulus* sp. *Helisoma* sp.	Orb snails
Physidae	Physa	
Ctenobranchiata		
Viviparidae	*Viviparous* sp.	Pouch snails
Pelecypoda		
Eulamellibranchia		
Sphaeridae	*Musculium* sp. *Pisidium* sp.	Freshwater mussel

Table 34. Percent composition of the most numerically abundant benthic macroinvertebrates and zooplankton collected from both the non-treated and treated regions in Lake Pearl.

Taxon	Non Treated	Treated
Benthic macroinvertebrates		
Chironomidae	27.0	22.0
Chaoboridae	27.0	33.0
Oligochaeta	34.0	35.0
Nematoda	7.0	4.0
Planaria	2.0	3.0
All others	3.0	3.0
	100.0	100.0
Zooplankton		
Cyclopidae	7.0	6.0
Diaptomidae	6.0	7.0
Diaphanosoma brachyurum	4.0	5.0
Daphnia ambigua	3.0	3.0
Eubosmina tubicen	18.0	18.0
Conochilus sp.	5.0	7.0
Keratella cochlearis	14.0	9.0
Polyarthra sp.	6.0	6.0
Hexarthra sp.	1.0	2.0
Asplanchna sp.	3.0	6.0
Diploclanis sp.	3.0	4.0
Brachionus havanaensis	4.0	2.0
All others	21.0	25.0
	100.0	100.0

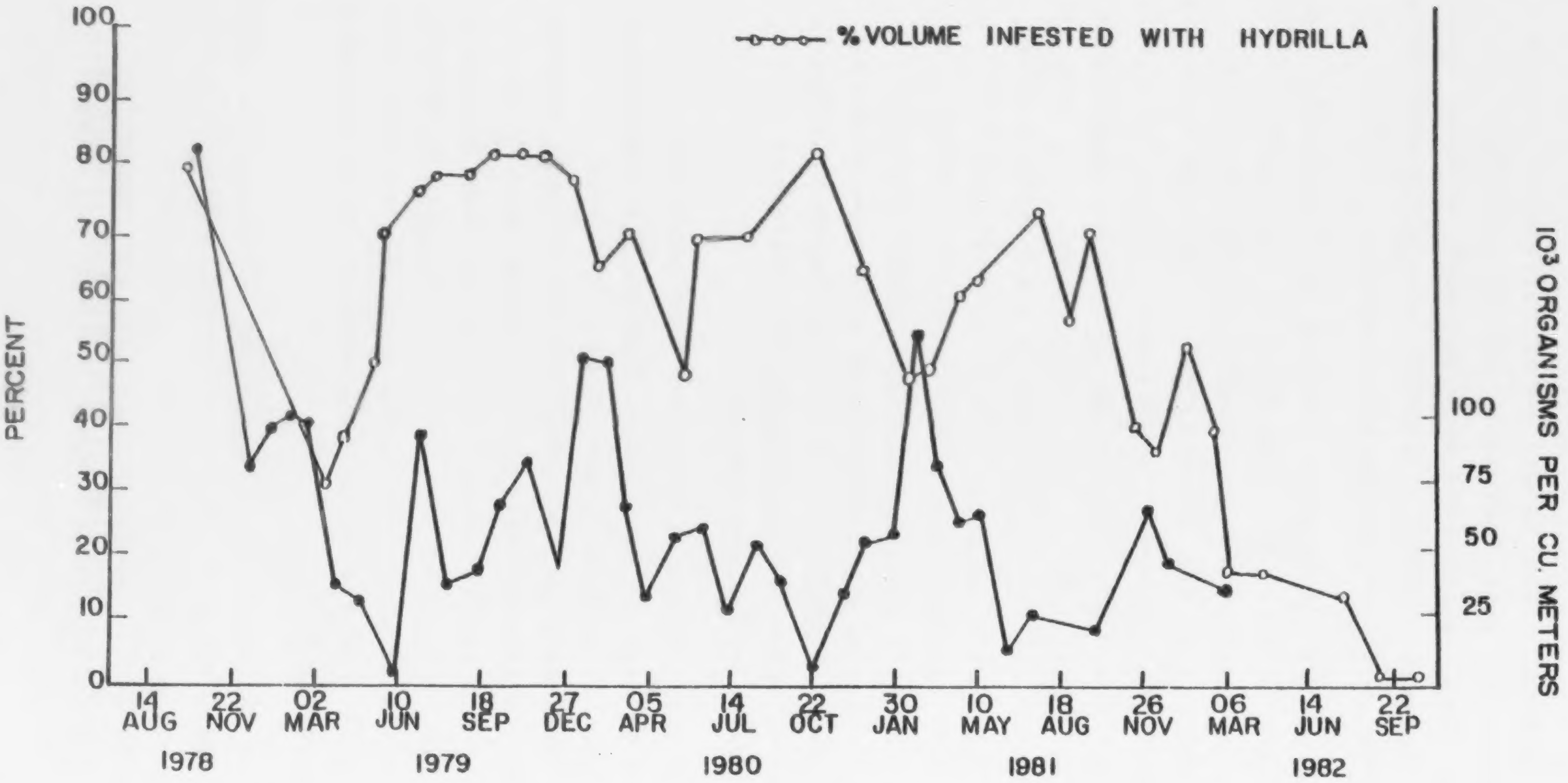


Figure 75. Total number of benthic organisms (•-•-•)collected from Lake Pearl anf the percent volume infested with hydrilla.

however, a general trend toward fewer numbers of benthic macroinvertebrates with decreasing hydrilla volume. In Orange Lake, where herbicides were not used, similar trends occurred. Greater numbers of benthic organisms were found in vegetative habitats than in open water.

A total of 55 zooplankton species were collected from Lake Pearl (Table 33). The diversity of Lake Pearl zooplankton community was due chiefly to the number of species collected in the littoral area. In both variety and numbers, rotifers dominated the samples. Of the 25 rotifers collected, four species (*Keratella cochlearis*, *Brachionus havaenensis*, *Polyarthra* sp. and *Diplochlanus* sp.) were the most frequently collected. Of the 22 cladoceran species collected, *Eubosmina tubicen*, a medium-sized species, dominated both littoral and pelagic samples. Three additional species, *Ceriodaphnia reticulata*, *Daphnia ambigua*, and *Diaphanasoma brachyurum* were also abundant. *Ceriodaphnia* and *Daphnia* sp. were more abundant in the pelagic areas, whereas *Diaphanasoma* was collected more frequently from vegetation samples.

Statistical analysis indicated that only one zooplankton species, a cladoceran (*Eurycercus lamellatus*), was significantly more abundant in the untreated portion of the lake. This species, however, was not a major species and is known to inhabit vegetation. After vegetation was removed from the treated end, this species was collected infrequently. All other species were collected from both treated and non treated lake areas, and species that were numerous throughout the study continued to be collected from both areas (Table 34).

Brooker and Edwards (1975), after reviewing the changes that occur when aquatic weeds are killed, concluded that most zooplankton population changes that occur are due to disappearance of the weeds (Figure 76). In order to determine the relationship between zooplankton and vegetation volume, total mean numbers, total mean numbers of

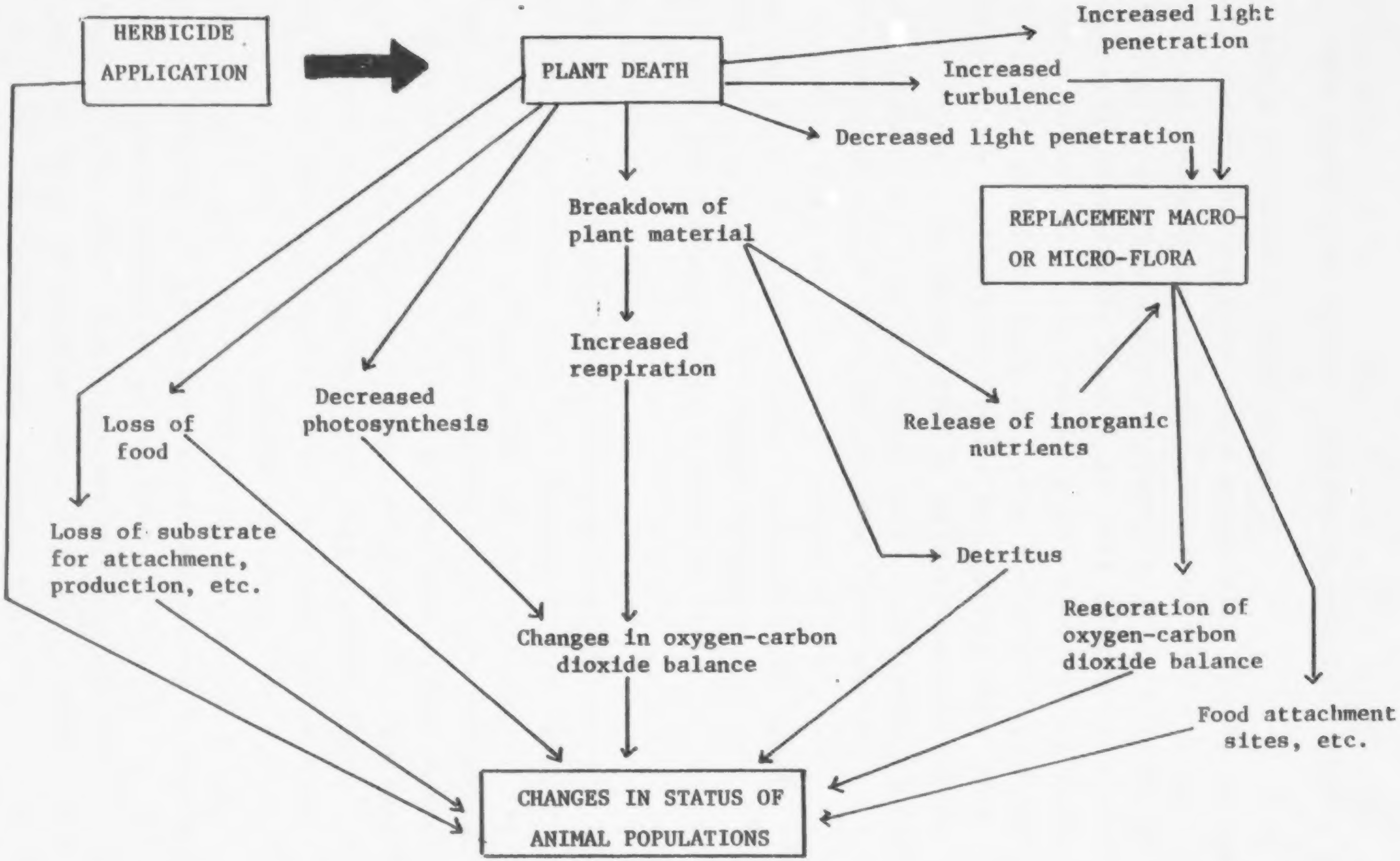

HERBICIDE APPLICATION
PLANT DEATH
Increased light penetration
Increased turbulence
Decreased light penetration
REPLACEMENT MACRO- OR MICRO-FLORA
Breakdown of plant material
Increased respiration
Loss of food
Decreased photosynthesis
Release of inorganic nutrients
Loss of substrate for attachment, production, etc.
Detritus
Restoration of oxygen-carbon dioxide balance
Changes in oxygen-carbon dioxide balance
Food attachment sites, etc.
CHANGES IN STATUS OF ANIMAL POPULATIONS

Figure 76. Effects of herbicide application and the destruction of submerged plants likely to be of consequence in determining faunal changes. From Brooker and Edwards, 1975.

pelagic species and total mean numbers of littoral zooplankton species were plotted against vegetation volume (Figures 77, 78 and 79). Total zooplankton numbers showed cyclic changes. Maximum numbers usually occurred in the winter months, with decreasing numbers in the summer and a minor peak in the fall. Although not statistically significant, there seemed to be a trend for total zooplankton numbers to increase as the volume of vegetation decreased (Figure 77). The increase in numbers of total zooplankton was due to the increase in pelagic forms. Although the number of pelagic forms was low during each summer, winter peaks increased each year (Figure 78). Littoral zooplankton showed similar seasonal oscillations as did the pelagic forms. It appears that peak winter numbers each year began to decline as vegetation volume decreased (Figure 79). Shireman and Watkins (unpublished data) and Watkins (1981) documented similar changes in Lake Baldwin, Florida, where zooplankton community change reflected changes in hydrilla volume.

The Lake Pearl zooplankton community is rich both in rotifers and cladocerans. Copepods, however, were represented by only a few species. Shireman and Martin (1978) reported that in Lake Wales, Florida, another hydrilla-infested lake, zooplankton was dominated by littoral cladocerans, but rotifers were poorly represented. Results obtained from other Florida studies indicate that the abundance of zooplankton groups may depend upon lake trophic state. Copepods tend to dominate in oligotrophic-mesotrophic lakes; rotifers dominate in eutrophic systems and cladoceran populations appear to vary depending upon food availability and predation (Blancher 1979) (Table 35). Noonan (1979) reports relationships between zooplankton abundance and chlorophyll a levels which also indicates that trophic state influences zooplankton.

In Lake Pearl, our results indicate that the aquatic herbicides used did not directly or adversely affect the

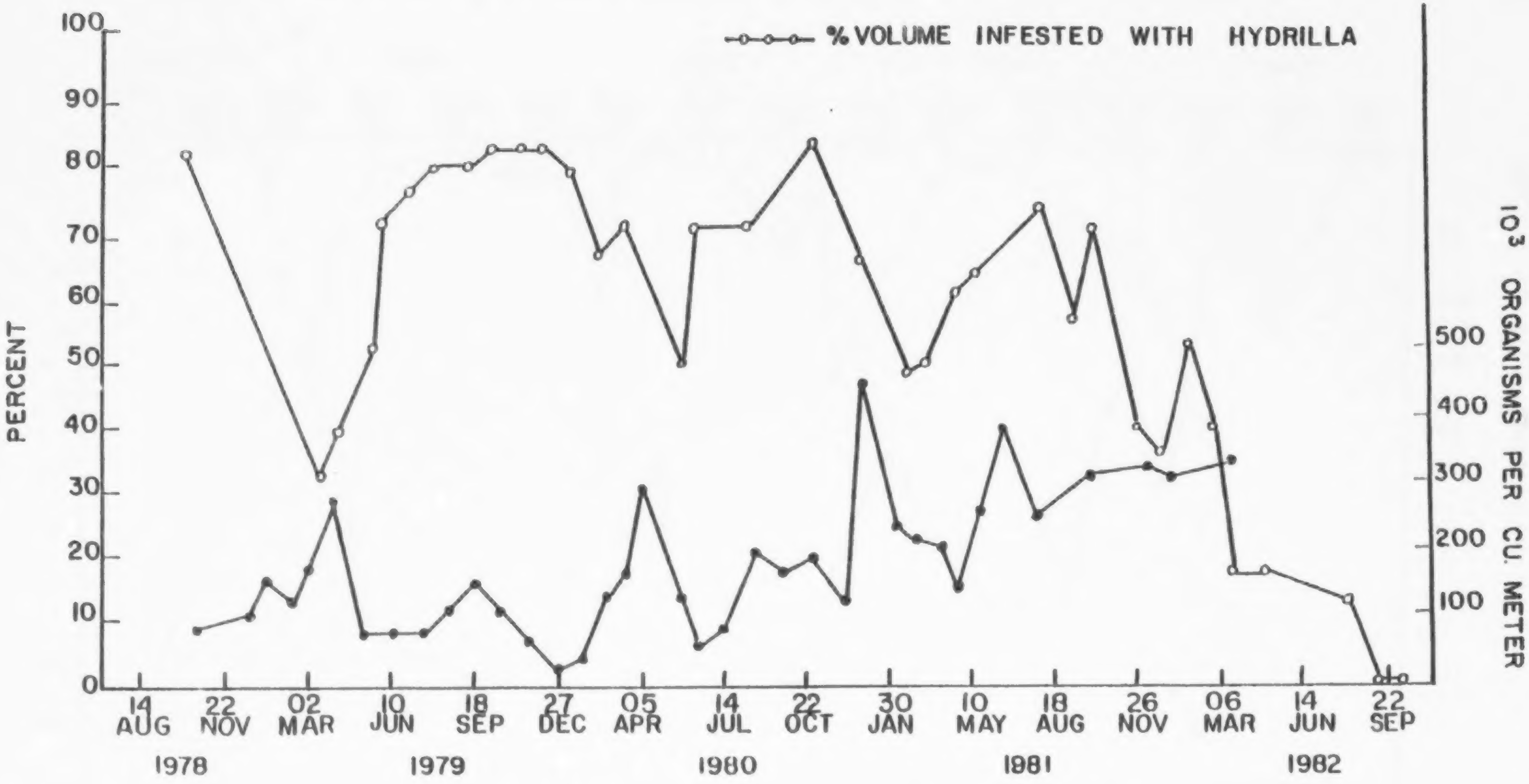


Figure 77. Total mean number of zooplankton (•—•—•) collected monthly from Lake Pearl, Florida, and the percent volume infested with hydrilla.

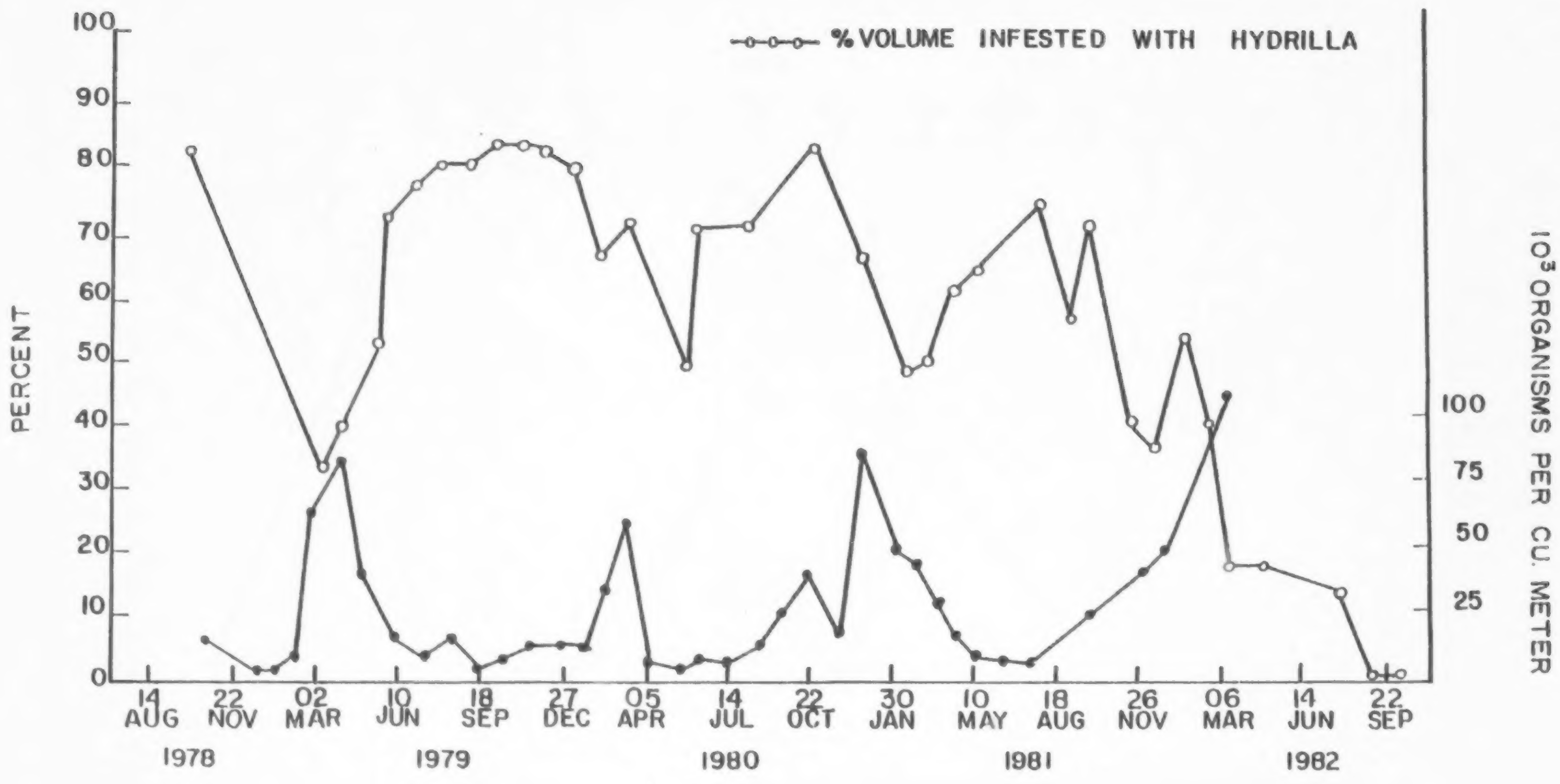


Figure 78. Total number of pelagic zooplankton (●—●—●) collected from Lake Pearl, Florida, and percent of the lake infested with hydrilla.

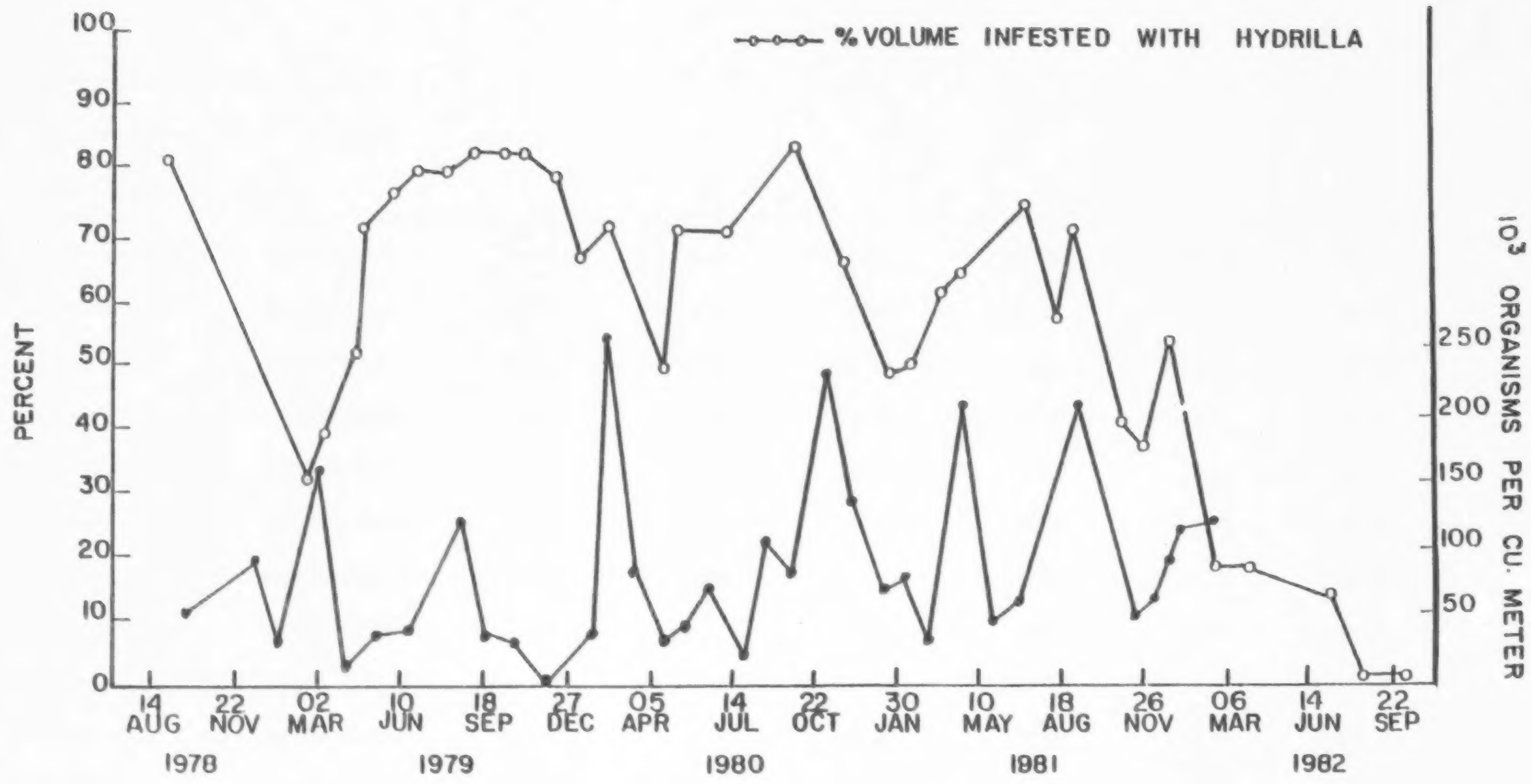


Figure 79. Total number of littoral zooplankton (•—•—•)collected from Lake Pearl and percent volume of lake infested with hydrilla.

Table 35. Percentages of average annual abundance and biomass of the major taxa in some Florida lakes.

Lake	Trophic State	Percent Annual Average Abundance			Percent Annual Average Biomass		
		Rotifers	Cladocerans	Copepods	Rotifers	Cladocerans	Copepods
Minneola	Oligotrophic	25.8	36.5	39.8	0.5	28.0	72.5
Sandhill	Oligotrophic	37.4	14.4	48.0	1.0	11.0	88.0
Anderson-Cue*	Oligotrophic	--	--	--	0.4	27.0	69.0
McCloud*	Oligotrophic	--	--	--	0.2	21.0	74.0
Kingsley	Mesotrophic	22.4	36.0	41.0	0.5	26.0	73.0
Conway	Mesotrophic	20.0	30.0	50.4	0.3	22.0	79.0
Little Conway	Mesotrophic	35.3	31.8	33.0	1.0	23.0	76.0
Gatlin	Mesotrophic	22.7	53.2	23.9	0.4	49.0	50.6
Wauberg	Eutrophic	78.0	5.9	15.9	5.0	13.0	81.0
Denham	Eutrophic	89.7	3.5	6.8	11.0	16.0	76.0
Thonotosassa†	Eutrophic	97.9	0.7	1.4	39.0	10.0	50.0

*After Maslin (1969).

†After Cowell _et_ _al_. (1976).

Table from Blacher (1979).

number and distribution of aquatic invertebrates. The herbicides used in Lake Pearl were applied at label recommendations and apparently did not attain concentrations toxic to either benthos or zooplankton. A review by Shireman et al. (1982) indicates that aquatic herbicides are relatively non-toxic to aquatic organisms in laboratory bioassay tests. Toxicity of herbicides can be affected by a number of physical and chemical factors. These factors are more easily controlled in the laboratory than in the natural environment. When herbicides are used according to label recommendations, however, they are nontoxic at the rates applied. In Lake Pearl, herbicides were applied, at most, to only 50% of the lake surface. These application rates add an additional margin of safety because final total concentrations were diluted 50%.

Orange Lake

All Orange Lake data were logarithmically transformed for statistical analysis. Analyses were conducted at each taxonomic level: phylum, class, order, family, genus and species where applicable. Significant differences between vegetated and nonvegetated habitats were determined by pooling all vegetated samples. A Student's t-test was used to test for differences caused by presence or absence of aquatic vegetation. Significant numerical differences among the four habitats (hydrilla, spatterdock, maidencane and natural open water) were determined utilizing an analysis of variance and a Duncan's multiple range test which ranked mean abundance among habitats. All statistical analyses were completed using the Statistical Analysis System (Barr et al. 1978). The term "significant'" is used when a statistical test indicated significance at $P<0.05$.

A total of 79 different invertebrate taxa were collected from the vegetated region (Table 36) and 51 taxa (65%) were collected from the profundal area. The vegetated area of the lake supported a significantly greater density (organisms/m²) of benthic macroinvertebrates than the

Table 36. Zooplankton and benthic macroinvertebrates collected from Orange Lake, Florida from four habitats: Nuphar (N), Panicum (P), Hydrilla (H) and Nonvegetated Open Water (O.W.).

Taxon		N	P	H	O.W.
Zooplankton					
Arthropoda					
Crustacea					
Cladocera					
Sididae	*Sida crystallina*	+	+	+	+
	Diaphanosoma brachyurum	+	+	+	+
	Latinopsis occidentalis	+	+	+	
Holopedidae	*Holopedium gibberum*	+	+	+	+
Daphnidiae	*Daphnia ambigua*	+	+	+	+
	Simocephalus vetulus	+	+	+	
	Ceriodaphnia reticulata	+	+	+	+
Chydoridae	*Chydorus sphaericus*	+	+		+
	C. hybridus	+	+		
	Alona rectangula	+	+	+	+
	A. gutatta	+	+	+	+
	A. affinis	+	+	+	+
	A. monocantha	+	+	+	+
	Dunhevedia crassa	+			
	Kurzia latissma	+	+	+	+
	Eurycercus lamellatus	+			
	Ilyocryptus spinifer	+	+		+
	Graptoleberis testudinaria	+	+	+	+
	Camptocercus rectirostris	+	+	+	+
	Pleuroxus denticulatus	+	+	+	
Bosminidae	*Bosmina tubicen*	+	+	+	+
Macrothricidae	*Macrothrix rosea*	+	+	+	+
Copepoda					
Calanodea	*Diaptomus floridanus*	+	+	+	+
Cyclopoida					
Rotifera					
Monogononata					
Ploima					
Brachionidae					
Brachioninae	*Brachionus havanaensis*	+	+	+	+
	B. angularis	+	+	+	+
	B. quadridentata	+	+	+	+
	B. caudatus	+	+	+	+
	Keratella cochlearis	+	+	+	+
	K. quadrata	+	+	+	+
	Kellicottia sp.	+	+	+	+
	Platyias patulus	+	+	+	+
	P. quadricornis	+	+	+	+
	Euchlanis sp.	+	+	+	+
	Manfredium sp.	+	+	+	
	Mytilina sp.	+	+	+	+
	Macrochaetus sp.	+	+	+	+
	Scaridium sp.	+	+	+	+

Table 36. Continued.

Taxon		N	P	H	O.W.
Lecaninae	*Lecane* sp.	+	+	+	+
	Monostyla sp.	+	+	+	+
Colurinae	*Lepadella* sp.	+	+	+	+
Synchaetidae	*Polyarthra* sp.	+	+	+	+
Asplanchnidae	*Asplanchna* sp.	+	+	+	+
Tricorceridae	*Trichocerca* sp.	+	+	+	+
Hexarthridae	*Hexarthra* sp.	+	+	+	+
Notommatidae	*Cephalodella* sp.	+	+	+	+
	Monommata sp.	+	+	+	+
	Scaridium sp.	+	+		
Ploesomatidae	*Ploesoma* sp.	+	+	+	+
Flosculariacea					
Testudinellidae	*Filina* sp.	+	+	+	+
	Pedalia sp.	+	+	+	+
Conochilidae	*Conochilus* sp.	+	+	+	+
Benthos					
Platyhelminthes					
Turbellaria					
Planariidae		+	+	+	+
Nematoda					
Adenophorea					
Dorylaimidae					
Dorylaimidae	*Eudorylaimus* sp.	+	+	+	+
Annelida					
Oligochaeta					
Haplotaxida					
Tubificidae	*Limnodrilus* sp.	+	+	+	+
Hirudinea					
Rhynchobdellida					
Glossiphoniidae	*Helobdella* sp.	+	+	+	+
Arthropoda					
Crustacea					
Decapoda					
Palacinmonidae	*Palaemonetes paludosus*	+	+	+	+
Amphipoda					
Talitridae	*Hyalella azteca*	+	+	+	+
Insecta					
Ephemeroptera					
Baetidae	*Callibaetis* sp.	+	+	+	+
Odonata					
Libellulidae	*Erythemis* sp.	+	+	+	
	Pachydiplax sp.	+			
	Parapoynx sp.	+			
Coenagionidae	*Cannacria* sp.		+	+	
Hemiptera	*Enallagma* sp.	+	+	+	+
Nocoridae					
Tricoptera	*Pelocoris* sp.	+	+	+	+
Hydroptilidae	*Orthotrichia* sp.	+	+	+	
	Oxyethira sp.	+	+	+	
	Oecetis sp.	+	+		

Table 36.Continued.

Taxon		N	P	H	O.W.
Lepidoptera					
Leptoceridae	*Leptocerus* sp.	+			
Hymphulidae	*Parapoynx* sp.	+			
Coleoptera					
Chrysomelidae	*Donacia* sp.	+		+	
Diptera					
Chaoboridae	*Chaoborus* sp.	+	+	+	+
Chironomidae		+	+	+	+
Ceratopogonidae		+	+	+	
Tabanidae	*Tabanus* sp.	+	+	+	
Mollusca					
Gastropoda					
Pulmonata					
Ancylidae	*Ferissia* sp.	+	+	+	
Planorbidae	*Gyraulus* sp.			+	
	Helisoma sp.	+	+	+	
Physidae					
Ctenobranchiata					
Viviparidae	*Physa* sp.	+	+	+	+
	Vivparous sp.	+	+	+	+
Pelecypoda					
Eulamellibranchia					
Sphaeridae	*Musculium* sp.	+	+	+	+

nonvegetated area. Total zooplankton numbers, however, were not significantly different between the two areas (Table 37). A change in community composition was evident between vegetated vs nonvegetated habitats. Among the vegetated habitats, the percent composition of the major taxa of zooplankton remained relatively constant, with copepods comprising approximately 40%, cladocerans 21% and rotifers 39%. The greatest number of rotifers were collected from the limnetic region and comprised approximately 55% of the total number. Copepods accounted for 36% and cladocerans 9% of the total.

All classes of benthic macroinvertebrates were collected in significantly greater numbers from vegetation (Table 38). The benthos of the profundal area of Orange Lake was comprised primarily of substrate inhabiting organisms. Ninety-one percent of the macroinvertebrates (annelids and dipterans) collected in the nonvegetated region were burrowers within the bottom substrate. Less than 65% of the vegetative-inhabiting macroinvertebrates were burrowing forms. Members of all families except Chironomidae and Chaoboridae and over 50% of the genera tested were collected at significantly greater numbers in vegetation. Among vegetative habitats, the greater variety of macroinvertebrates encountered within vegetative habitats was attributed to the presence of motile rapaceous organisms.

Spatterdock supported the greatest number of zooplankton taxa (48), followed by maidencane (45), hydrilla (44) and open water (38) (Table 39). Arthropod zooplankton comprised the greatest percentage of the plankton collected from all three vegetated habitats while rotifers comprised the greatest percentage collected from open water (Figure 80). Results indicated that neither total zooplankton abundance, nor the abundance of the three major taxa, cladocerans, copepods or rotifers demonstrated significantly greater numbers among the four habitats. Species of

Table 37. Mean total number zooplankton per cubic meter and benthic macroinvertebrates per square meter collected from Orange Lake, Florida (± 95% confidence interval).

POOLED HABITATS	ZOOPLANKTON	BENTHOS
Vegetated	177601.0 ± 14965.3	2867.9 ± 352.3
Nonvegetated	216718.7 ± 31901.0	1069.7 ± 477.3

Table 38. Mean number of zooplankton per cubic meter and benthic macroinvertebrates per meter square by class, between vegetated and nonvegetated regions in Orange Lake, Florida (± 95% confidence interval).

TAXON	VEGETATED	NON VEGETATED
Zooplankton		
Crustacea	109832.0 ± 10819.2	97756.3 ± 13753.9
Monogonata	67769.1 ± 7208.5	118962.4 ± 28863.0
Benthos		
Turbellaria	126.2 ± 32.5	22.3 ± 24.7
Adenophorea	88.8 ± 49.1	82.7 ± 65.8
Oligochaeta	1317.8 ± 223.8	247.5 ± 188.4
Hirudinea	190.5 ± 52.3	62.3 ± 61.9
Crustacea	412.0 ± 108.6	111.5 ± 88.4
Insecta	688.0 ± 122.1	554.1 ± 254.6
Gastropoda	26.5 ± 10.2	1.8 ± 0.9
Pelecypoda	9.9 ± 4.0	2.0 ± 0.8

Table 39. Mean number of zooplankton per cubic meter and benthic macroinvertebrates per meter square in Orange Lake Florida (values in a row followed by the same letter have overlapping 95% confidence intervals).

TAXON	NUPHAR	PANICUM	HYDRILLA	OPEN WATER
Zooplankton				
Cladocera				
Sididae (Family)	2138.0^{a}	1614.7^{a}	4879.0^{b}	333.0^{c}
Diaphanosoma brachyurum	1640.0^{a}	1037.0^{a}	1953.7^{a}	314.6^{b}
Macrothrix rosea	343.0^{a}	16.7^{b}	223.6^{a}	4.2^{b}
Camptocercus rectirostris	214.0^{a}	270.0^{b}	1000.0^{b}	11.5^{c}
Rotifera				
Monostyla sp.	4129.0^{a}	948.0^{b}	4885.0^{a}	637.5^{b}
Keratella cochlearis	10025.0^{a}	15154.2^{b}	9517.2^{a}	40777.0^{c}
Benthos				
Annelida				
Hirudinea (Class)	75.5^{a}	230.0^{b}	257.8^{C}	62.3^{d}
Oligochaeta (Class)	916.0^{a}	1168.3^{b}	1860.7^{b}	247.5^{c}
Crustacea				
Palaemonetes paludosus	8.2^{a}	2.4^{b}	4.6^{ab}	0.0^{c}
Total benthic macroinvertebrates	2244.0^{a}	2586.4^{a}	3752.3^{b}	1067.2^{c}

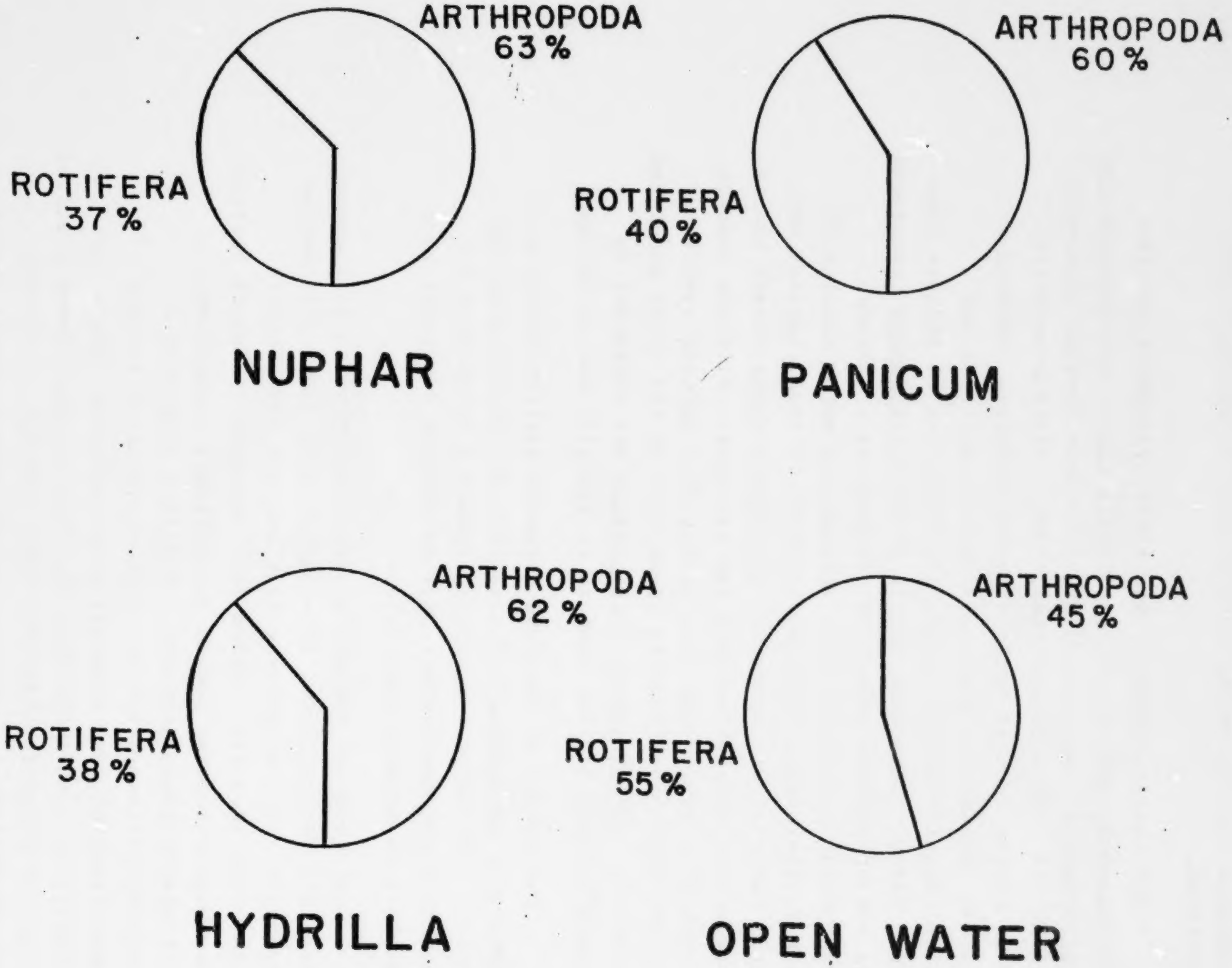


Figure 80. Percentage, by number, of zooplankton from habitats in Orange Lake, Florida.

copepods did not exhibit significant differences among habitats.

One family, Sididae, and three cladoceran species, *Diaphanosoma brachyurum*, *Macrothrix rosea*, and *Camptocercus rectirostris* demonstrated significantly greater abundance among the four habitats (Table 39). Sididae revealed significant habitat preference for hydrilla compared to native vegetation, but all vegetated habitats had significantly higher population densities of Sididae than open water. Edmondson (1959) noted *Diaphanosoma brachyurum* (a representative genera of Sididae) is a littoral cladoceran associated with marshes and weedy margins of lakes; therefore, hydrilla provided an ideal habitat for this group of cladocerans. *Macrothrix rosea* showed habitat preference for spatterdock and hydrilla. Although numbers inhabiting maidencane were higher than natural open water, values were significantly lower than in the other vegetated habitats. *Camptocercus rectirostris* was collected in significantly greater numbers in hydrilla and maidencane.

Two genera of rotifers revealed habitat selectivity. *Keratella cochlearis* had significantly higher densities within open water. *Monostyla* showed a preference for hydrilla and spatterdock, but maidencane densities were similar to natural open water.

The greatest variety of macroinvertebrate taxa among habitats was collected from spatterdock (25), followed by hydrilla (23), maidencane (21) and the nonvegetated profundal area (10) (Table 36). Results indicated benthic macroinvertebrates pooled collectively demonstrated a difference among habitats. Hydrilla supported a significantly greater total mean number of benthic macroinvertebrates than any other habitats (Table 39). Spatterdock and maidencane had significantly lower standing crops of macroinvertebrates than hydrilla, but their macroinvertebrate communities were significantly greater than those collected in open water. Standing crops were not different in terms of total numbers between spatterdock or maidencane. Among benthic macroinvertebrates, annelids dominated maidencane and hydrilla habitats while arthropods dominated spatterdock and open water (Figure 81). The composition of arthropods within the open water community, however, was totally different than the vegetated habitats. Greater than 99% of the arthropod numbers in open water were chironomids and chaoborids and standing crops of both groups were equal. Representatives of almost all groups of aquatic arthropods (tricopterans, ephemeropterans and odonates) were collected in vegetated habitats. Chironomid standing crops were significantly larger than chaoborid populations within maidencane and spatterdock. Although 95% confidence limits for chaoborids and chironomids within hydrilla did overlap, chironomid numbers tended to be greater. Three individual species of macroinvertebrates [leeches (Helobdella), oligochaetes (Limnodrilus) and grass shrimp (Palaemonetes paludosus)] had significant habitat preferences. All three had higher standing crops within vegetated habitats. Hydrilla and maidencane were the preferred habitats for leeches and oligochaetes. Freshwater shrimp were not collected in open water. Maximal densities of freshwater shrimp were collected in spatterdock.

Welaka Ponds

A total of 44 zooplankton taxa was collected from the Welaka ponds. Rotifers were the most abundant of the identified species (25), followed closely by cladocera (21 species), copepoda were not identified to species, but grouped as cyclopoida, calanoida and nauplii.

Copepods were the most numerous zooplankton collected (51.7%) with nauplii accounting for 75.9% of the copepods numbers. Rotifers were the next most abundant group (38.7% of the total). Keratella sp. and Polyarthra sp. were the dominant rotifer species. Cladocerans constituted only 9.6% by number of the total zooplankton fauna. The three most abundant cladocerans were Diaphanasoma brachyurum (12.5%), Eubosmina coregoni (11.1%) and Alona rectangula (9.5%).

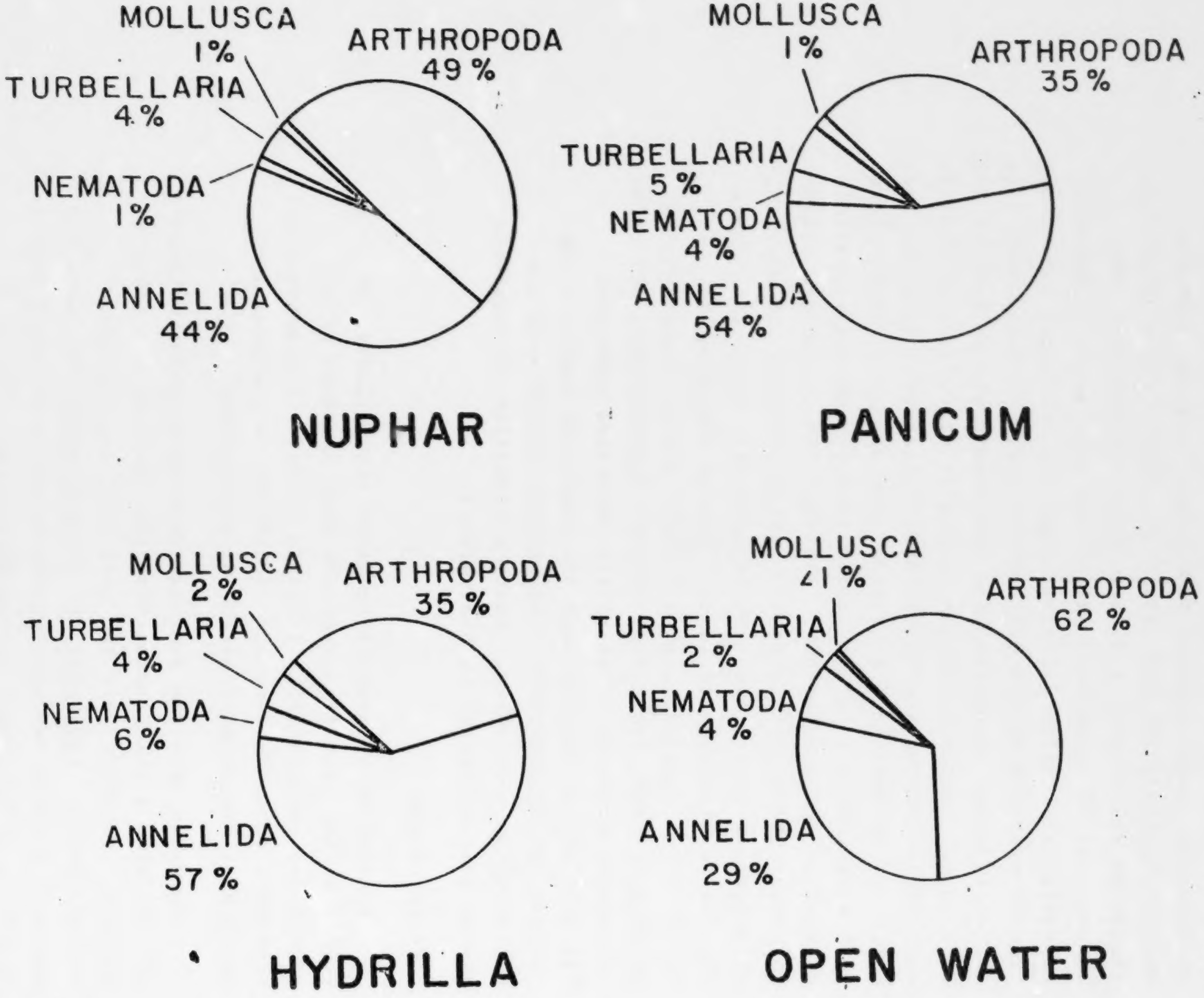


Figure 81. Percentage, by number, of benthic organisms from habitats in Orange Lake, Florida.

Total zooplankton ranged from a mean of 203 organisms per liter in the 30% herbicide vegetation control ponds to 324 organisms per liter in the fertilized ponds (Table 40). The mean number collected from the fertilized ponds was significantly higher than the mean number for the 100% vegetation and the 30% herbicide ponds.

The mean total number of rotifers (Table 40) were most abundant in the fertilized ponds (157/L) and the 100% herbicide control ponds (122/L). Fewest rotifers were collected from the 100% grass carp control ponds.

The grass carp treatment ponds contained the greatest mean number of cladocera, ranging from 28 to 37 organism per liter (Table 40). The 100% vegetation and 30% vegetation control ponds were intermediate in mean number of cladocera (25 and 24 organisms per liter). The remaining herbicide treatment (30 and 60%) ponds contained the fewest cladocera (14/1).

The mean number of copepods (150 and 149 per liter) were collected from grass carp treatment ponds, whereas the lowest mean number was collected from the 30% herbicide control pond. Two grass carp treatment ponds had greater mean numbers of copepods than all herbicide treatments, except for the 70% vegetation control ponds where greater mean numbers of copepods were collected (Table 43).

In general, the grass carp ponds had greater numbers of large zooplankton (copepoda and cladocera) than all other treatment ponds, whereas herbicide and fertilizer ponds had greater numbers of small zooplankton (rotifers). Fertilization ponds contained the greatest number of total zooplankton.

The dominant cladocerans in all ponds were *Diaphanosoma brachyurum*, *Bosmina coregoni* and *Alona rectangula* (Table 41). Among the grass carp ponds *B. coregoni* was dominant followed by *D. brachyurum* and *A. rectangula*. *Daphnia ambigua* was dominant in the 60 and 100% vegetation

Table 40. The mean number of zooplankton per liter from all Welaka pond samples for each treatment.

Treatment	Copepoda	Cladocera	Rotatoria	Total
100% vegetation	100.4	24.9	90.0	215.4
Grass Carp 30%	150.4	30.6	85.5	266.5
Grass Carp 60%	137.4	27.9	83.0	248.3
Grass Carp 100%	149.3	37.0	72.0	258.3
Herbicide 30%	96.6	23.6	82.7	202.8
Herbicide 60%	145.9	13.9	87.4	247.2
Herbicide 100%	111.1	13.9	121.9	246.9
Fertilization	146.0	19.8	159.3	323.5

Table 43. Organisms identified in benthic samples from ponds located at Welaka, Florida.

Class	Order	Family	Genus
Coelenterata	Hydroida	Hydridae	Hydra
Turbellaria	Tricladida	Planariidae	
Annelida		Lumbriculidae	
		Aeolosomatidae	Aeolosoma
	Oligochaeta	Naididae	Chaetogaster
			Pristina
			Nias
			Stylaria
		Tubificidae	
	Gnathobdellida	Hirundinae	
Crustacea			
	Amphipoda	Talitridae	Hyalella
	Emphemeroptera	Caenidae	Caenis
		Baetidae	Baetis
	Odonata	Aeshnidae	Anax
		Libellulidae	Callibaetis
			Celithemis
			Erythemis
			Erythodiplax
			Pachydiplax
			Somatochlora
			Tetragonueria
			Tramea
		Coenagrionidae	Enallagma
	Hemiptera	Nocoridae	Pelocoris
		Nepidae	Ranatra
		Belostomatidae	Belostoma
		Corixidae	Hesperocorixa
	Trichoptera	Hydroptilidae	Oecetis
			Orthotrichia
			Oxyethira
		Leptoceridae	Leptocerus
	Lepidoptera	Hymphulidae	Eoparagyractis
			Paraponx
	Coleoptera	Haliplidae	Peltodytes
		Dytiscidae	Bidessus
		Hydrophilidae	Berosus
			Paracymus
		Chrysomelida	Donacia
	Diptera	Culidicae	Chaoborus
			Culex
		Chironomidae	
		Podonominae	
		Ceratopogonidae	Dasyhela
			Palpomyia
		Tabanidae	Chrysops
Mollusca	Gastopoda	Ancylidae	Ferrissia
		Planorbidae	Gyraulus
			Helisoma
		Physidae	Aplexa
			Physa
	Pelecypoda	Sphaeridae	Musculium

treatments and Macrothrix rosea and Chydorus sphaericus were the dominant cladocerans in the 30 and 60% control ponds. Grass carp ponds generally contained larger zooplankton. The dominant species among the herbicide treatments were A. rectangula, B. coregoni, D. brachyurum, M. laticornis and M. rosea.

In all herbicide treatments, Alona rectangula and M. rosea were important. C. shapericus and M. laticornia were important components in the 30 and 60% vegetation control ponds. In the 30% percent vegetation control ponds B. coregoni was the dominant species and was collected most frequently. C. reticulata was the most dominant cladoceran species in the 100% vegetation control ponds followed by A. rectangula and M. rosea other species of importance were D. brachurum, and M. laticornis.

Only three species of cladocerans were dominant in the fertilized ponds: D. brachyurum, C. sphaericus and C. reticulata (Table 41). D. brachyurum was the most numerous single species. Three other species, although not considered among the dominant cladocerans, which did occur frequently were B. coregoni and A. rectangula and A. monacantha.

Among the many species of rotifers, Keratella spp. were the dominant organisms in all treatments. The fertilized treatment ponds had the highest mean number of Keratella spp., whereas the 100% vegetation control ponds contained the lowest number (Table 42). The numbers in all other treatments ranged between 35 and 58 per liter. The second most abundant rotifer was Polyarthra sp. and it was most abundant in the 100% vegetation control ponds. Fewest numbers were collected from the 30% grass carp control ponds. All herbicide treatment and fertilized ponds contained greater mean numbers of Polyarthra sp. than did the grass carp ponds.

Table 41. Mean number per liter of dominant cladoceran species from all Welaka pond samples for each treatment.

Cladoceran species	Vegetation 100%	Grass Carp			Herbicide			Fertilization
		30%	60%	100%	30%	60%	100%	
Diaphanasoma brachyurum	1.8	3.0	5.3	3.6	2.7	0.7	1.5	5.3
Daphnia ambigua	0.3	0.2	1.9	2.3	0.2	0.4	0.2	0.5
Ceriodaphnia reticulata	3.3	0.1	0.3	1.0	1.5	0.6	0.2	1.5
Alona rectangula	3.0	4.4	2.4	1.1	2.6	2.3	1.7	0.8
Bosmina coregoni	0.3	4.4	3.2	6.0	4.0	0.3	2.1	0.9
Macrothrix rosea	2.5	2.8	0.9	0.6	1.2	1.0	1.8	0.4
Chydorus sphaericus	1.1	1.6	1.1	0.3	1.8	1.4	0.5	1.9
Alona monocantha	1.1	0.3	1.7	0.2	0.7	0.7	0.7	0.8
Illocryptus spinifer	0.3	0.3	0.2	0.7	0.2	0.1	2.1	0.3
Macrothrix laticornis	1.9	0.8	0.5	0.4	1.6	2.4	0.3	0.3

Criteria for dominance set at 1.0 organism per liter.

Table 42. Mean numbers per liter of dominant rotatoria species from all Welaka pond samples for each treatment.

Rotatoria species	Vegetation	Grass Carp			Herbicide			Fertilization
	100%	30%	60%	100%	30%	60%	100%	
Keratella spp.	35.0	49.0	58.2	18.6	39.2	45.5	54.0	125.2
Polyarthra sp.	11.0	9.6	12.1	14.9	15.2	15.7	28.6	22.0
Lecane sp.	16.7	3.5	2.1	1.4	3.8	3.3	2.3	2.8
Vanoyella sp.	7.6	2.6	6.7	2.5	2.0	2.4	2.9	14.9
Monostyla sp.	13.3	5.8	4.4	3.0	2.6	6.9	4.5	3.9
Platyias patulus	7.1	0.3	2.9	0.5	2.6	2.6	0.6	0.6
Hexarthra sp.	1.3	3.9	4.2	5.6	2.0	3.9	5.2	7.6
Synchaeta sp.	0.1	3.9	2.5	9.3	11.8	0.8	5.1	1.1
Brachionus angularis	0.3	9.9	0.1	0.9	0.8	0.4	7.4	11.5

Criteria for dominance set at 3 organisms per liter.

Monostyla sp. ranked third in total abundance and was most abundant in the 100% vegetation ponds. Other dominant genera were Hexarthra sp. Synchaeta sp, Lecane sp, Brachionus angulata, Vanoyella sp., and Platyias patulus.

Although the total number of organisms varied according to treatment, seasonal or monthly trends were similar in all ponds. Greater number of organisms were collected prior to the time when treatment effects become noticeable (January 1981). Peak numbers of zooplankton occurred in all ponds except in the grass carp ponds where 30% vegetation was removed during Summer 1980. After January 1981, the numbers of zooplankton decreased considerably reaching low levels in all ponds during Fall 1981 (Figures 82 through 89). It appears that either herbicides, grass carp or fertilizer treatments did not cause the seasonal distribution of these organisms to change. After vegetation was controlled to treatment levels, all ponds responded identically including the control ponds. The number of zooplankton in the 100% control ponds was less than in the other levels but greater than in the ponds where 100% vegetation remained.

Forty-nine benthic invertebrate taxa were collected from the 24 Welaka, Florida ponds (Table 43). In comparison to lakes Pearl and Orange, a greater variety of benthic macroinvertebrates were collected from these ponds.

In order to determine treatment effects, a multi-regression analysis was run on total organism numbers where the class variables were treatments and ponds within treatments. Differences were not statistically different among treatments in respect to time, which indicates that the type and amount of control did not determine macroinvertebrate abundance. Mean number of organisms according to treatment ranged from 65 to 77 organisms/sample (Table 44).

Even though statistically significant differences did not occur in total abundance, some macroinvertebrate groups

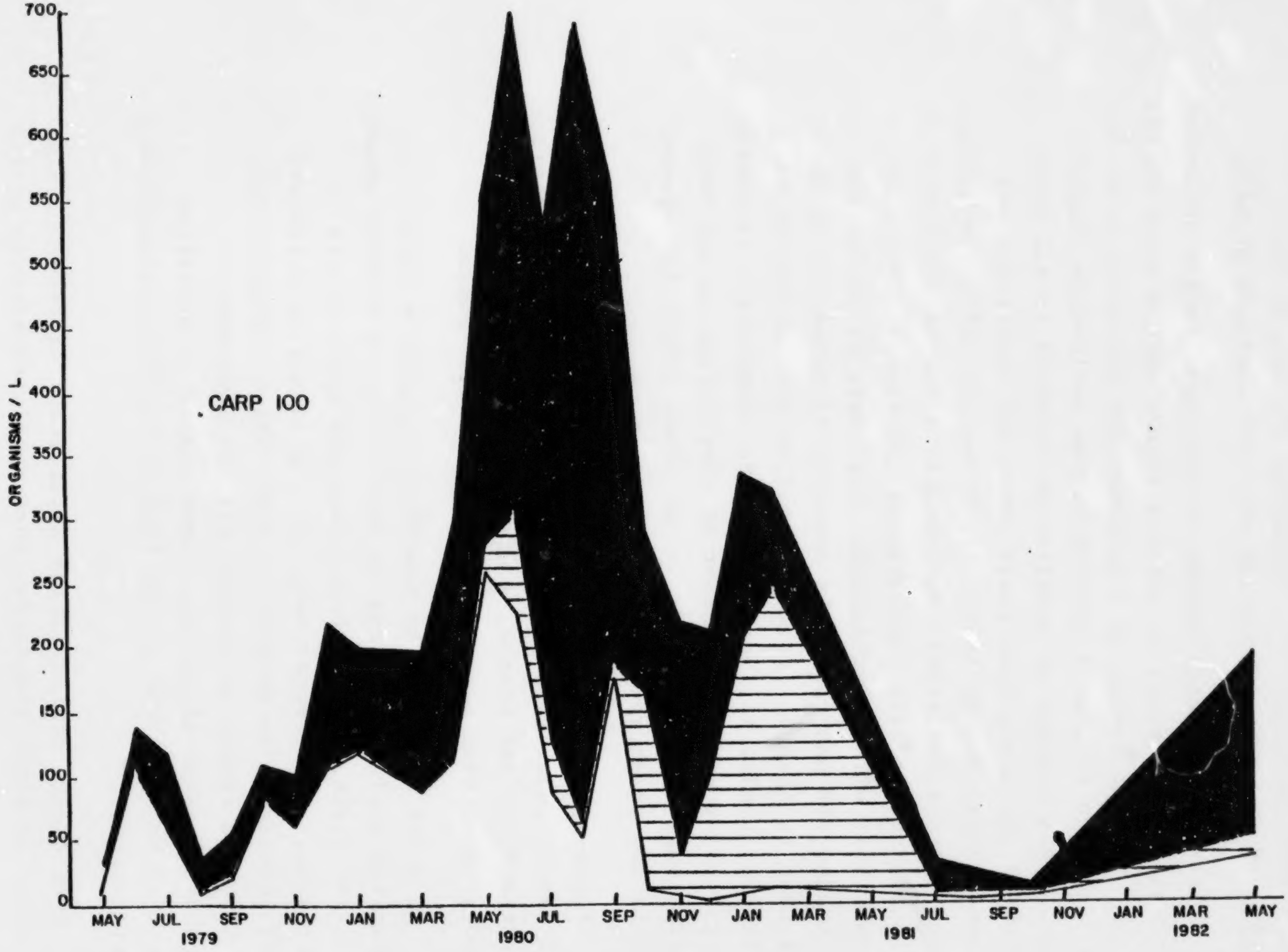


Figure 82. Mean total number of zooplankton per liter from 100% grass carp control ponds, Welaka, Florida (rotifers □ , cladocerans ▤ copepods ■).

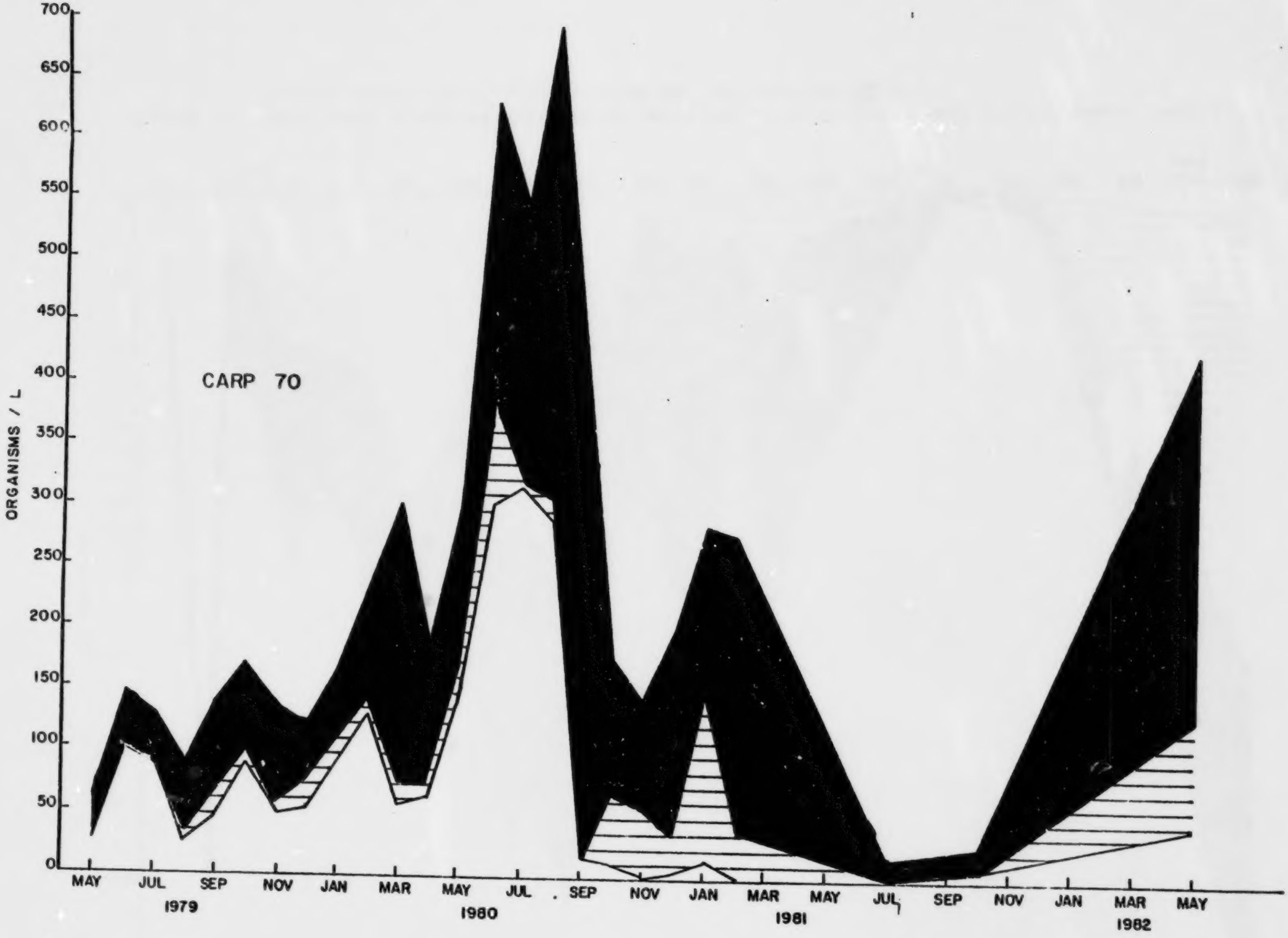


Figure 83. Mean total number of zooplankton per liter from 70% grass carp control ponds, Welaka, Florida (rotifers ☐ , cladocerans ▤ and copepods ■).

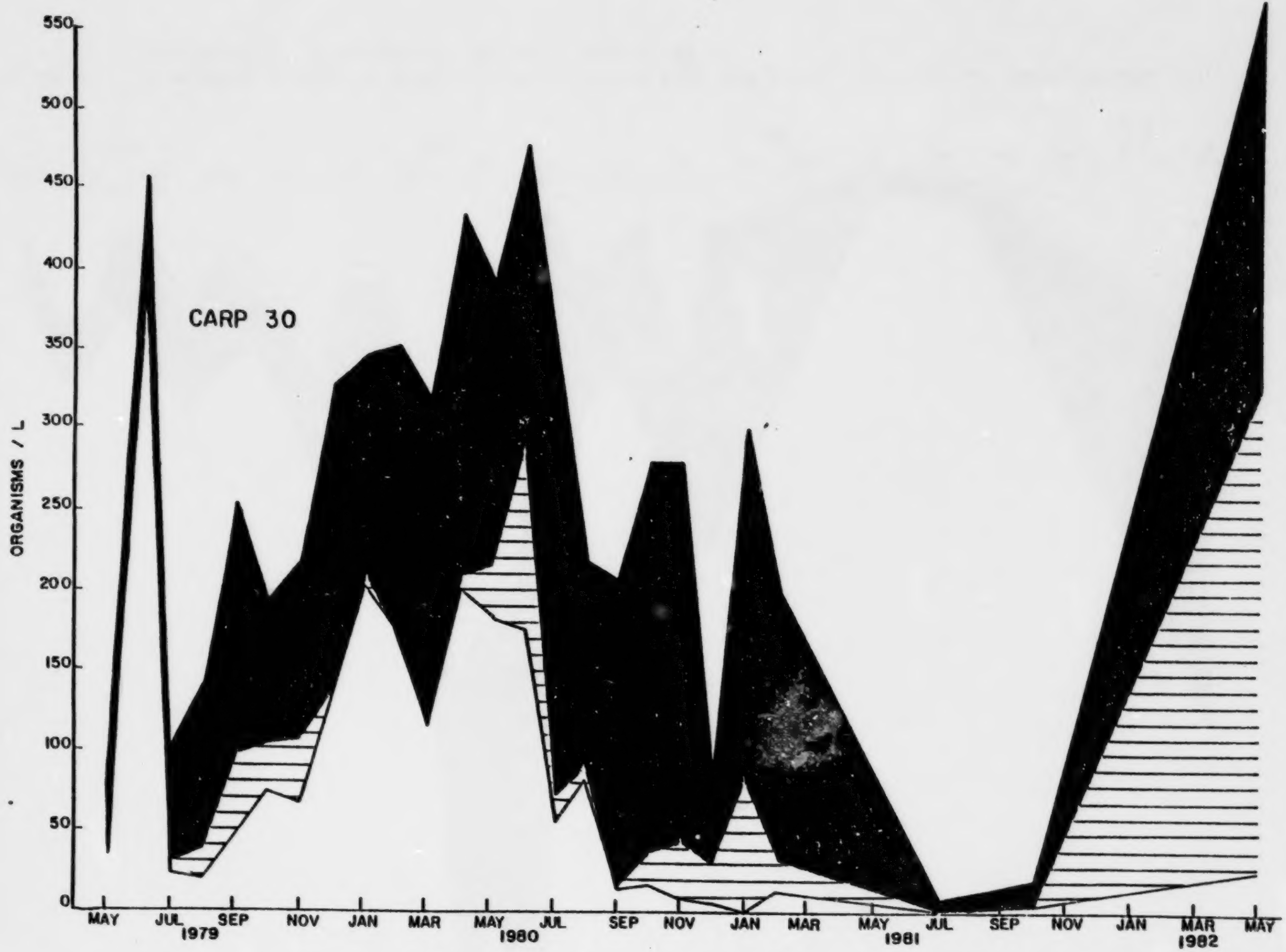


Figure 84. Mean total number of zooplankton per liter from 30% grass carp control ponds, Welaka, Florida (rotifers ☐ , cladocerans ▤ and copepods ■).

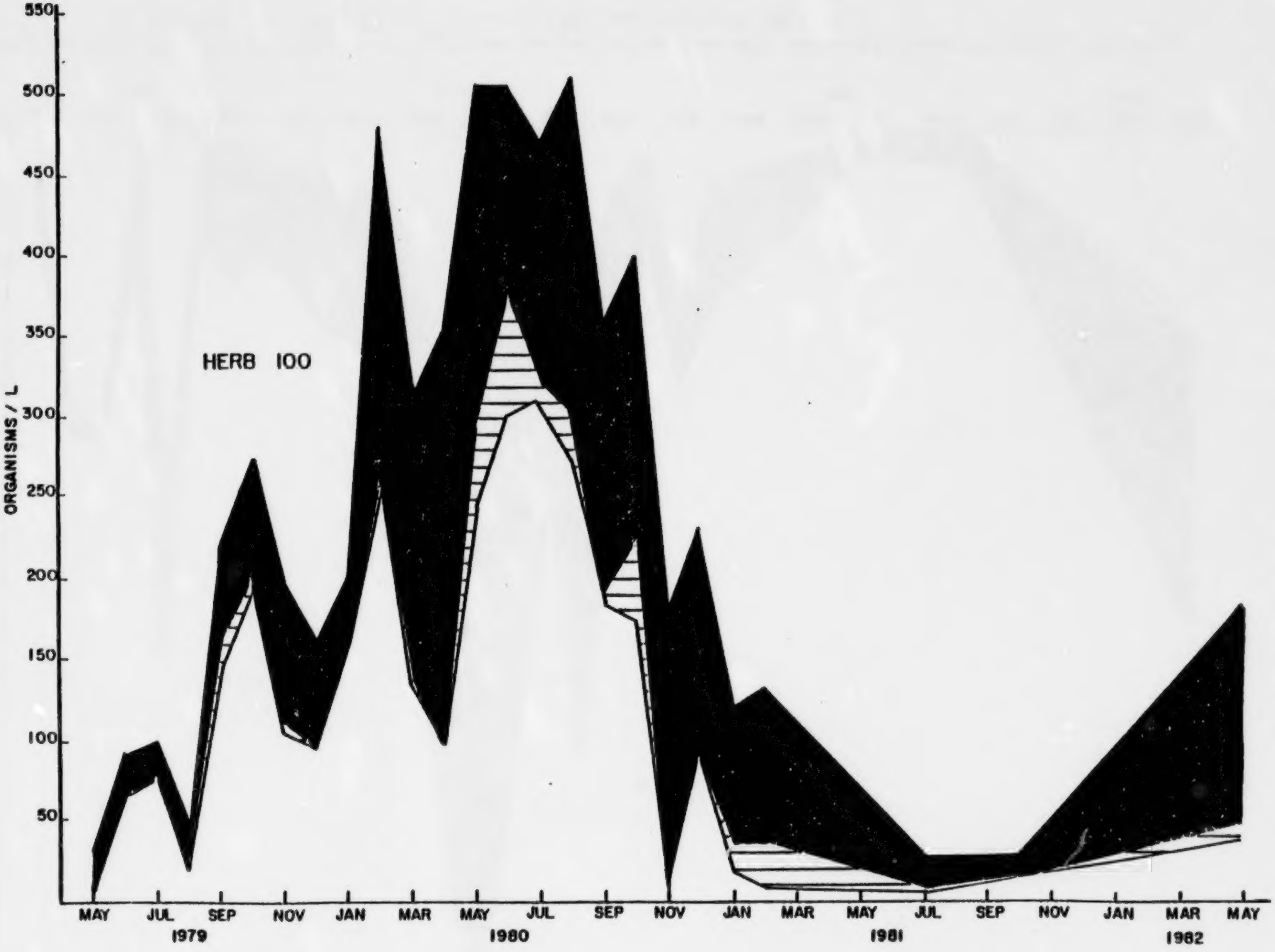


Figure 85. Mean total number of zooplankton per liter from 100% herbicide control ponds, Welaka Florida (rotifers ☐ , cladocerans ▤ and copepods ■).

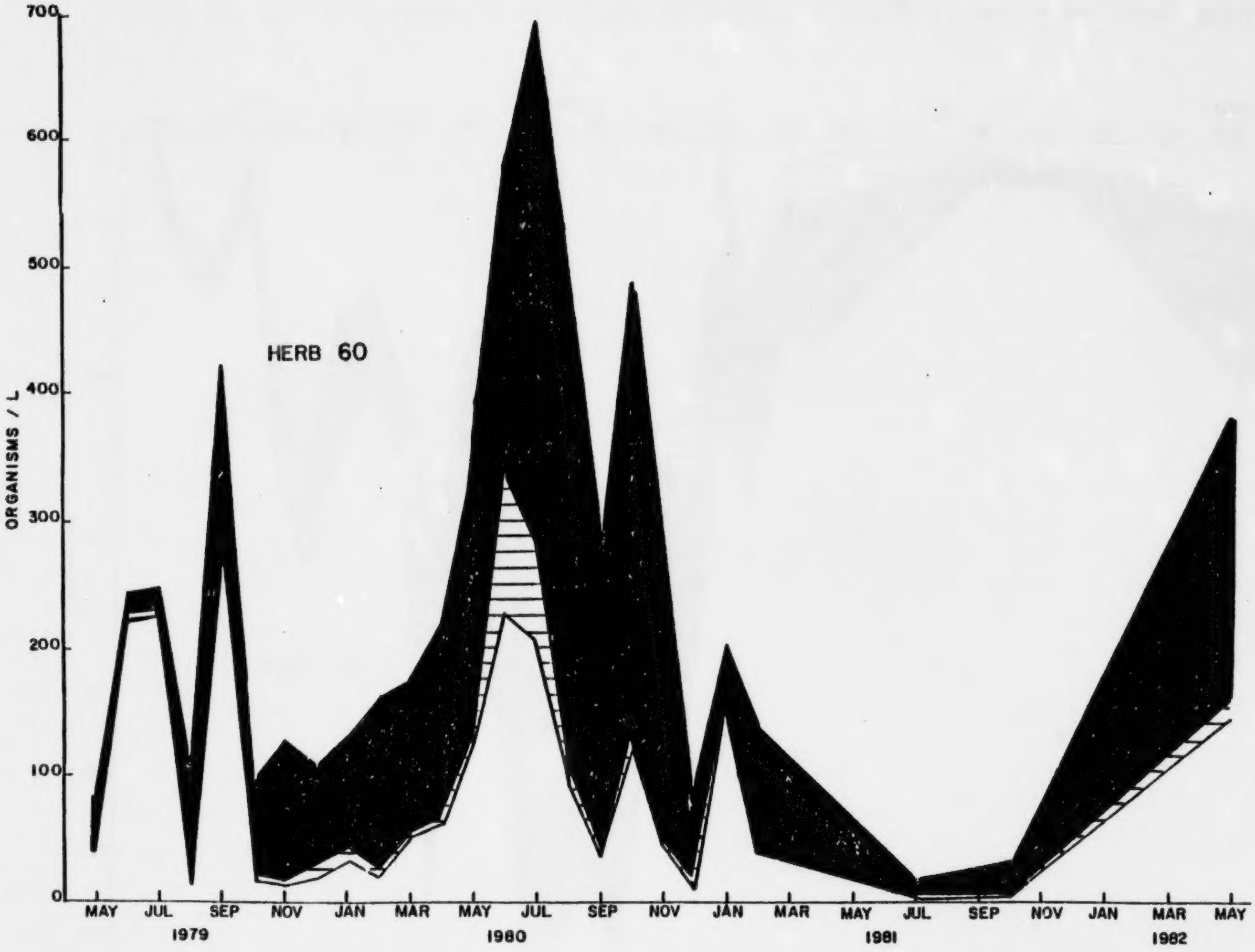


Figure 86. Mean total numbers of zooplankton per liter from 60% herbicide control ponds, Welaka, Florida (rotifers ☐ , cladocerans ▤ and copepods ■).

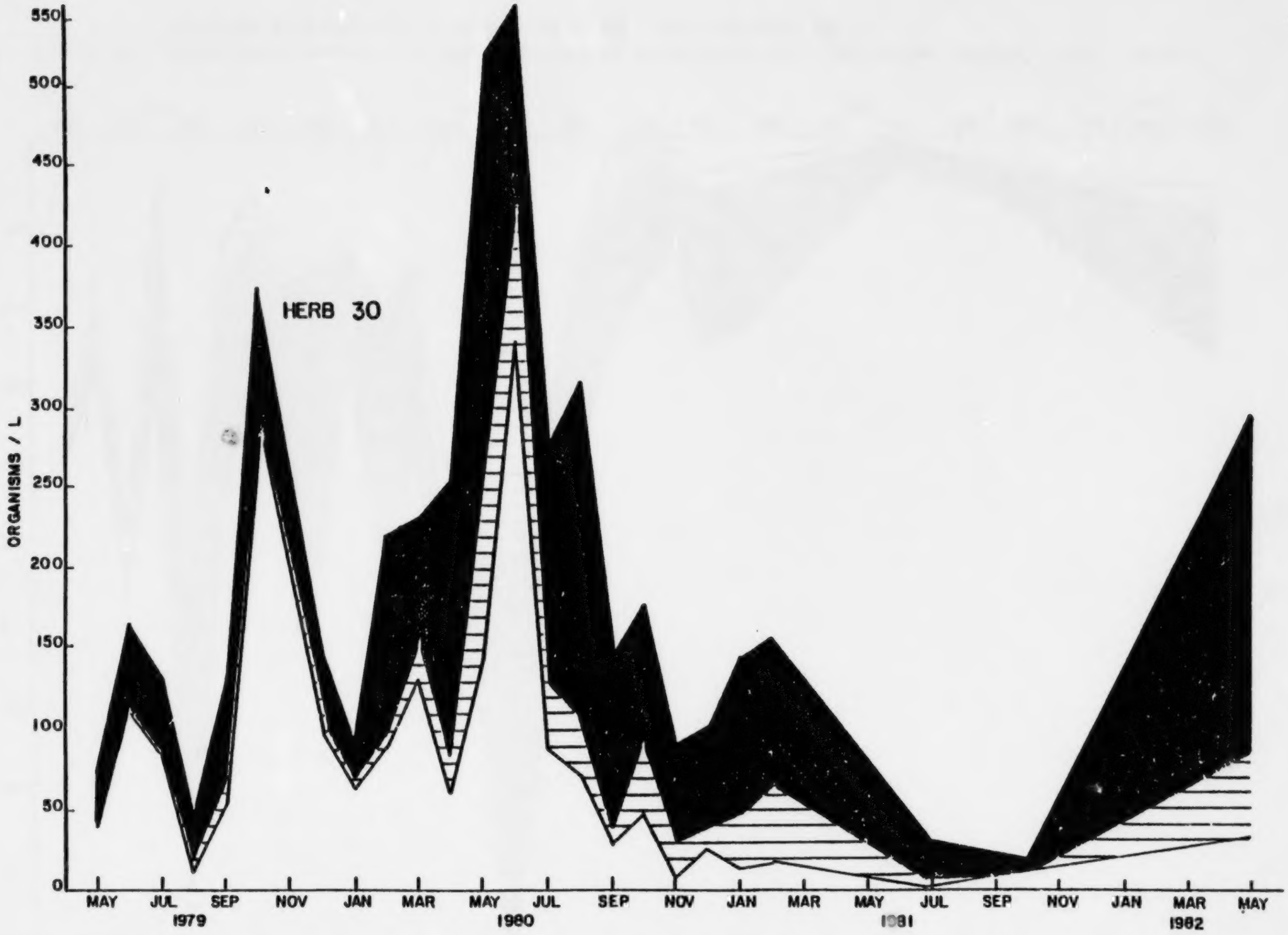


Figure 87. Mean total number of zooplankton per liter from 30% herbicide control ponds, Welaka, Florida (rotifers ☐ , cladocerans ▤ and copepods ■).

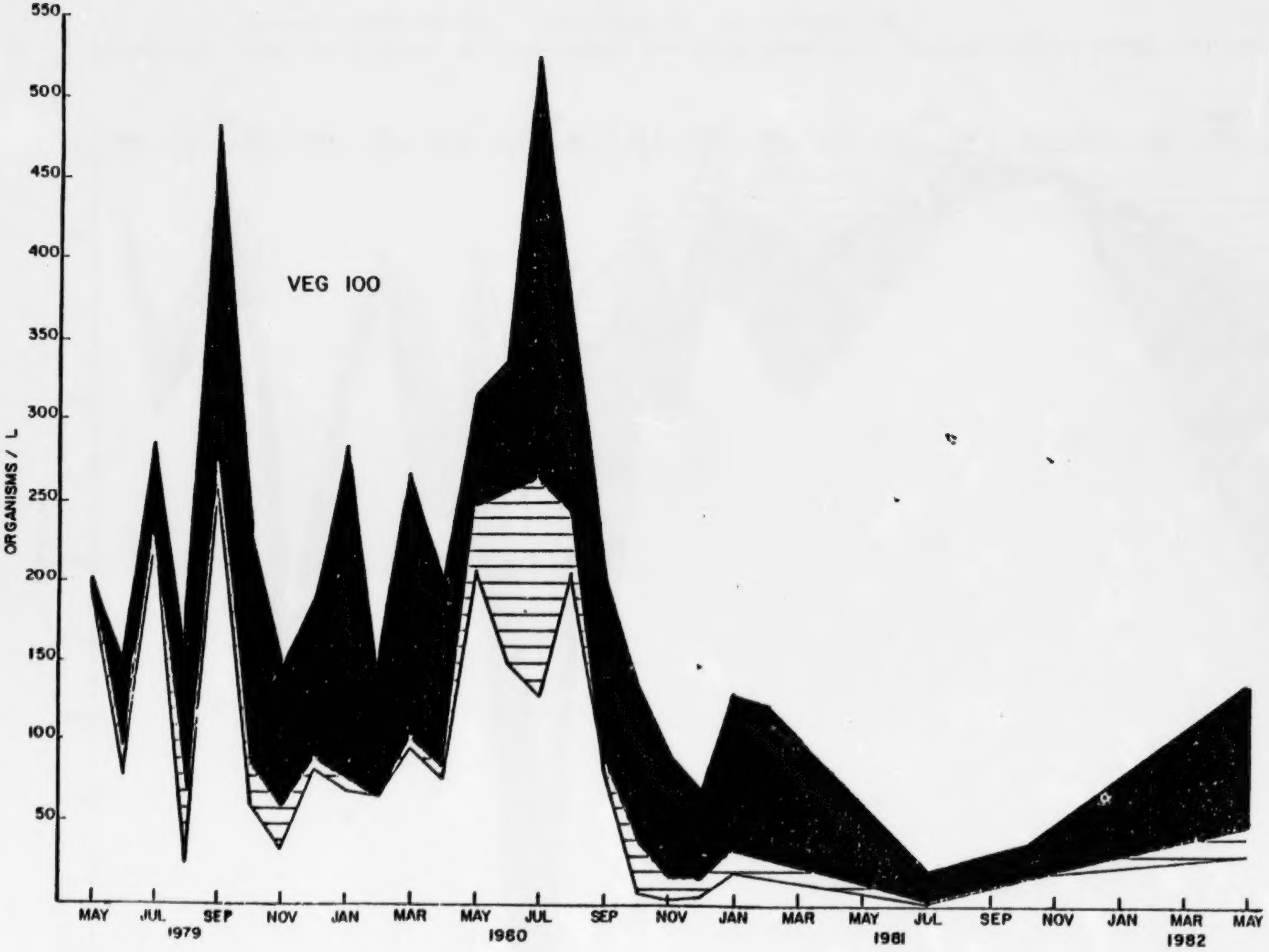


Figure 88. Mean total numbers of zooplankton per liter from 100 vegetation control pond, Welaka, Florida (rotifers □ , cladocerans ▤ and copepods ■).

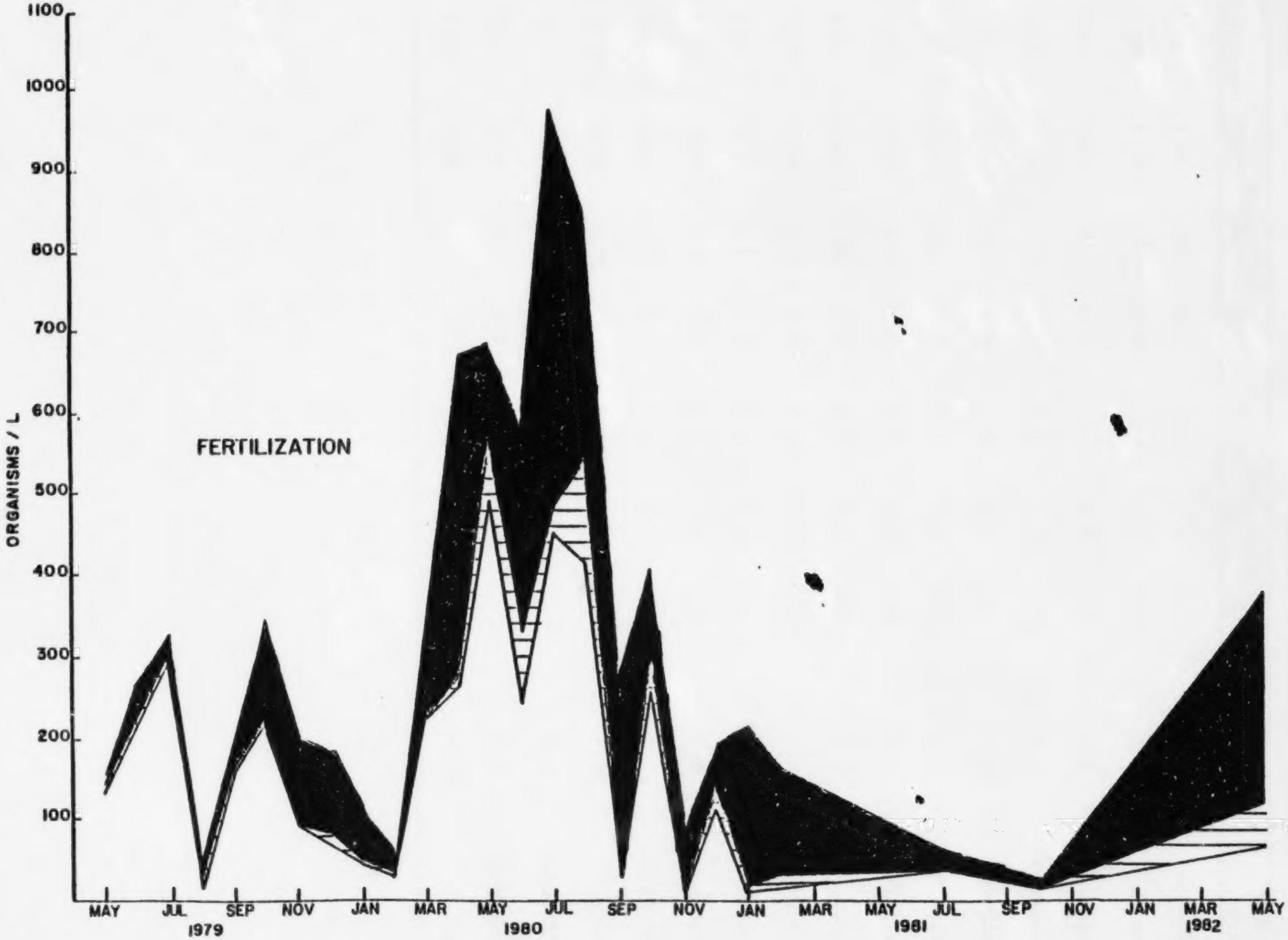


Figure 89. Mean total number of zooplankton per liter from fertilization control pond, Welaka, Florida (rotifers ☐ , cladocerans ▤ and copepods ■).

Table 44. Mean number per sample for orders of benthic invertebrates from each treatment collected at Welaka.

Benthic	Vegetation	Grass Carp			Herbicide			
Orders	100%	30%	70%	100%	30%	70%	100%	Fertilization
Nematoida	0.1	0.1	0.3	0.2	0.1	0.1	<0.1	0.3
Hydroida	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tricladida	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Oligochaeta	29.9	31.3	45.5	38.5	37.0	41.3	40.7	39.5
Gnathobdellida	<0.1	0.1	0.3	<0.1	<0.1	0.1	0.2	0.1
Amphipoda	2.8	2.0	2.9	1.9	2.2	1.4	2.5	1.7
Emphemeroptera	0.6	0.7	0.8	1.1	1.0	0.8	0.8	0.7
Odonata	0.4	0.4	0.1	0.1	0.3	0.2	0.1	0.2
Hemiptera	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Trichoptera	2.5	2.0	2.3	1.8	1.7	1.4	1.5	2.7
Lepidoptera	0.1	0.2	0.1	0.1	0.1	0.2	<0.1	0.1
Coleoptera	0.1	0.2	0.3	0.1	0.2	0.1	0.2	0.2
Diptera	23.7	18.6	18.5	14.5	18.8	20.9	19.2	22.0
Gastropoda	6.8	6.2	3.8	4.1	4.5	4.2	4.7	4.0
Pelecypoda	2.1	3.1	1.9	7.0	1.6	2.3	4.2	4.7
Total	69.2	65.1	77.1	69.6	67.7	73.1	74.3	76.3

were more abundant than others. Oligochates and dipterans (chaoborids and chironomids) were the most abundant group followed by gastropods, pelecypods, tricopterans and amphipoda (Table 44).

Sixty percent carp control ponds and fertilized ponds contained the greatest mean number of macroinvertebrates. Generally forms that burrow in the substrate were most numerous in treatment ponds when vegetation was removed and creeping crawling forms (odonates, tricoptera, and dipterans) were more abundant in completely vegetated ponds.

Aquatic plants provide niches for the existence of many different animal species. As the aquatic flora increases in abundance and variety, the associated fauna also increases (Rosine 1955; Mclachlan 1969; Quade 1968). Zooplankton and benthic macroinvertebrates have preferences for specific vegetation types (Krecker and Lancaster 1933; Frohne 1938; Smyly 1952; Straskraba 1964). Thus, the abundance and diversity of aquatic invertebrate populations can be directly influenced by the amount and species of aquatic plants present. Smyly (1952) and Straskraba (1964) noted that the abundance and productivity of littoral, vegetation inhabiting zooplankton coincided with an increase in the level of aquatic vegetation. Cowell and Hudson (1967) found 7 to 30 times greater production of macroinvertebrates in the vegetated versus nonvegetated profundal region of two Missouri River reservoirs. McLachlan (1969) noted an increase in the abundance, biomass, and variety of benthic macroinvertebrates accompanied the increase in aquatic macrophytes.

Cladocerans and copepods, which prefer aquatic plants, are forms that either feed among them, or, owing to their larger size, use aquatic plants to avoid predation (Green 1967; Hutchinson 1967; Whiteside and Harmsworth 1967). The preference of rotifers for the nonvegetated lake region may be due to their ability to avoid predation, because of their smaller size. They also seem to exhibit a physiological avoidance of aquatic plants (Hutchinson 1967; Hasler and Jones 1949).

The greater number and variety of benthic macroinvertebrates in the vegetated region of Orange Lake is similar to results of other studies. Muttowski (1918) and Eggleton (1931) noted that the profundal region supported fewer numbers and variety of benthic macroinvertebrates. In their studies, the profundal region was comprised predominantly of burrowing, substrate inhabiting forms, while the littoral region supported motile rapacious forms. This is identical to our findings. Most of the macroinvertebrates collected in vegetation were shredders, collectors or scrapers (Cummings 1973) and are potentially subject to greater predation. (Werner and Hall 1974, Kislalioglu and Gibson 1976, and O'Brien et al. 1976). Both food and predation are the main factors influencing macroinvertebrate distribution.

The greatest number of benthic macroinvertebrates collected from hydrilla samples is probably related to plant morphology. Krecker and Lancaster (1939) and Andrews and Hasler (1943) found that plants with greater leaf dissection, and hence greater surface, area, harbored greater numbers of macroinvertebrates. Hydrilla has numerous small leaves on a central stem which offers attachment sites for aufwuchs and grazing macroinvertebrates. Although dense stands of aquatic vegetation, especially hydrilla, provides for greater abundance and variety of benthic macroinvertebrates, excessive densities of hydrilla are detrimental to forage and sportfish. Prey organisms in dense vegetation can avoid predators (Crosman 1959; Stein and Magnuson 1976). Crower and Cooper (1978) demonstrated that moderate levels of vegetation might offer the best solution as fish growth was increased in moderate vegetation levels over low and high levels. They attributed this, in part, to prey availability. Colle and Shireman (1980) and Maceina and Shireman (1982) hypothesized that growth, numbers and biomass of sportfish were reduced in hydrilla infested lakes due to reduced prey availability. In these studies, and others, fish stunted at a size where they had advanced from feeding primarily upon zooplankton to benthic macroinvertebrates.

Among the many factors which influence invertebrate populations, the type and density of vegetation has a very important effect. It is evident that lack of vegetation, or too much vegetation, directly influences invertebrates and ultimately can influence fish production. Consequently, management of aquatic plants should be directed toward encouraging growth of those plants with an open growth form (e.g., maidencane and spatterdock) and limiting those submersed plants which produce extensive dense mats (hydrilla), where although a greater number of macroinvertebrates may be present, they are less available to predation by fish.

Fish

Blocknets

Lake Pearl

Both total fish standing crop and biomass declined with the elimination of submerged vegetation in 1982. Total numbers decreased from 37,739 fish/ha in 1980 to 1,587 fish/ha in 1982. Biomass decreased from a peak in 1979 of 215.1 kg/ha to 53.3 kg/ha in 1982 (Table 45). Examination of average fish weight revealed a reverse trend with vegetation removal. The reduction in total numbers and biomass and the increase in average fish weight is due to the absence of large populations of small vegetation dwelling species and a large decrease in bluegill <120 mm TL. The decrease in vegetation dwelling species was caused by habitat removal, while the large decline in small bluegill was probably due in part to bass predation.

Annual fluctuations in species numbers, according to blocknet data occurred each study year. Maximum numbers of

Table 45. Total number and weights (kg) of fish collected with blocknets in Lake Pearl.

Species	Number 1978	1979	1980	1981	1982	Weight 1978	1979	1980	1981	1982
Florida gar	12	0	0	0	0	4.1	5.0	0	0	0
Longnose gar	6	25	0	0	0	6.0	51	0	0	0
Gizzard shad	59	4	0	0	0	29	3.0	0	0	0
Redfin pickerel	6	0	12	28	0	.2	0	.9	1.0	0
Golden shiner	80	2923	902	34	3	9.0	29	46	2.0	<.1
Grass carp	0	0	0	6	3	0	0	0	13.3	12.4
Taillight shiner	3	0	0	0	0	3.0	0	0	0	0
Lake chubsucker	15	189	74	133	59	4.0	52.3	9.4	21	25
Yellow bullhead	3	0	0	0	0	.5	0	0	0	0
Brown bullhead	22	4	0	130	0	3.0	<.1	0	3.4	0
American eel	0	0	0	3	0	0	0	0	.91	0
Golden topminnow	6697	280	15	642	0	4.0	.34	<.1	.4	0
Bluegin killifish	374	0	3	96	0	<.1	0	<.1	<.1	0
Mosquitofish	497	165	0	170	0	.1	<.1	0	<.1	0
Least killifish	494	0	0	3	0	<.1	0	0	<.1	0
Brook silversides	0	342	124	40	553	0	.2	<.1	<.1	.5
Pygmy sunfish	105	0	0	0	0	<.1	0	0	0	0
Bluespotted sunfish	16311	1293	6240	5153	0	14.0	1.3	3.0	7.3	0
Warmouth	1417	1305	852	3696	3	9.0	13.0	4.0	20	<.1
Bluegill	2757	3487	28362	12616	787	31	12	51	104	12
Dollar sunfish	176	111	3	0	0	.3	.3	<.1	0	0
Redear	303	272	1010	574	124	5.0	10	6.0	9.0	5.0
Spotted sunfish	9	0	0	0	0	.2	0	0	0	0
Largemouth bass	176	189	124	383	40	23	25	4.4	26.4	9.0
Black crappie	40	354	9	68	9.0	6.3	12.4	.5	3.0	.9
Swampdarter	46	25	9	108	6	<.1	<.1	<.1	<.1	<.1
Total	29608	10968	37739	23883	1587	152.1	215.1	125.7	212.2	53.3

species (23) were present in 1978 with minimal numbers (10) in 1982. As in Orange Lake, these changes were attributed to incidental occurrence by single or low numbers of individual species that could be characterized as having low population densities within Lake Pearl. The almost total erradication of all submersed vegetation in 1982 resulted in the elimination of two species from block net samples (golden topminnows and bluespotted sunfish). These species had large annual populations prior to 1982. These species, were also eliminated from Orange Lake collections when hydrilla declined.

Gizzard shad were not encountered in lake Pearl after 1980. The only shad collected in 1978 and 1979 were large adults. Dense hydrilla at coverage levels >90% in Lake Pearl probably prevented gizzard shad fry from filter feeding for small phytoplankton and zooplankton, thereby causing little or no survival of year classes. The existence of a small adult population was probably due to the large fish feeding on the bottom and removing Aufwuchs from submersed vegetation (Baker et al. 1971).

DuRant (1980) demonstrated that for Florida fishes there are definite species assemblages associated with aquatic vegetation. He found that fishes common to Florida lakes are grouped into three major categories: A) species strongly associated with vegetation for their entire life; B) species associated with dense vegetation but usually living in shallow water and having relatively low population densities; and C) fishes found in dense submersed vegetation while young, but change to open water or sparse vegetation at maturity. Lake Pearl data, when grouped by DuRant assemblages (Table 46), revealed severe reductions of group A fish due to the elimination of the vegetated habitat which is required by these fishes. Group B fishes underwent a large decrease after 1978 to non-collection by 1982. The large numbers of group B fish in 1978 was due to the large standing crop of pygmy sunfish and least killifish. These

Table 46. Number of fish in assembledge categories in Lake Pearl (Assembledge based on DuRant 1980).

Category	Years				
	1978	1979	1980	1981	1982
A	25376	5966	8012	9791	6
B	608	0	12	31	0
C	3146	4480	29514	13406	1479

species normally do not have high standing crop values in the presence or absence of vegetation. The numbers of Group C fishes also declined during 1982 due to a reduction in the large standing crop of bluegill <120 mm.

The dominant forage fishes changed as submersed vegetation was removed. Bluespotted sunfish were the dominant small forage fish in 1978, and were only surpassed in numbers by young bluegill in 1980 and 1981. Golden shiners peaked at 2923 individuals/ha in 1979, comprising a significant segment of the potential forage base in that year. As hydrilla decreased in 1981 and was eliminated in 1982, their standing crop underwent a marked decline. Swingle (1946) reported golden shiners could not be used as a continual forage base for largemouth bass due to high vulnerability to bass predation. Piper et al. (1982) states that adhesive golden shiner eggs are deposited in algae and vegetation; therefore, the decline in golden shiner standing crop is related to both an elimination of spawning habitat coupled with a large increase in mortality due to largemouth bass predation. Warmouth population densities increased to high levels in 1981 making it the third most abundant species within Lake Pearl. After the elimination of submersed macrophytes, warmouth standing crop decreased to 3 fish/ha. Bluegill and brook silverside comprised the major forage base during 1982.

Bluegill and largemouth bass length frequency distributions shifted quickly when hydrilla was removed from the system (Table 47). Large reductions in standing crops of juvenile and young-of-year of both species occurred. Bluegill length frequency distributions through time indicate that by 1980 the bluegill population was stunted. Bluegill size distributions during 1980 and 1981 were dominated by small individuals with more than 98% <120 mm. Hydrilla attained coverage levels in excess of 90% by 1977 in Lake Pearl; therefore, it took approximately three years before fish population structure underwent a shift to

Table 47. Mean number per hectare by size group for largemouth bass and bluegill in Lake Pearl, Florida.

Size Group	1978		1979		1980		1981		1982	
	Largemouth bass	Bluegill	Largemouth bass	Bluegill	Largemouth bass	Bluegill	Largemouth bass	Bluegill	Largemouth bass	Bluegill
40	3	216		25		6027	216	5193		698
80	3	1074	45	741	19	50018	321	5934		25
120	52	1192	45	753	148	253	25	13492	12	303
160	31	219	33	1515	43	346	62	401		525
200	12	49	12	449	25	74	49	204	25	25
240	15	6	17		12	6	25	6		
280	19		29				37		25	
320	28						25		6	
360	6								6	
400	3		4							
440	3						6			
480										
520										
560										
600			4							

nonharvestable individuals. The immediate change in largemouth bass length frequency distribution during 1982 was caused by bass predation after submersed vegetation was removed. The decrease in young-of-year bass (<160 mm) was not caused by a decrease in bass bedding activity or spawning success, but to predation on juvenile fish by larger bass. Bass bedding was observed in 1982 and fry schools were seen during the March 1982 electrofishing sample. By the June electrofishing sample, however, no young-of-year bass were collected or observed. Large decreases in young-of-year and juvenile bass and bluegill standing crops is characteristic when hydrilla is eliminated. Orange Lake showed the identical trend as hydrilla decreased in 1978. Orange Lake fish also underwent similar population trends as populations were skewed to small individuals by 1981. This occurred approximately two years after hydrilla coverage was in excess of 65%.

A student's t-test was utilized to test for differences in habitat selection in harvestable sportfish during 1980 and 1981 when hydrilla levels were different between the treated and non-treated portions of Lake Pearl. Herbicide application was initiated in March 1980 and by August 1980, plant height was significantly lower within the treated region. When blocknet sampling was conducted in October 1980, plant height in both ends of the lake were not significantly different.

Redear did not select for a particular habitat in either year. Bluegill did not select for either area during 1980, but in 1981 they were found in significantly higher numbers in hydrilla in the nontreated end of the lake. Harvestable largemouth bass were found in significantly higher numbers within the treated region in 1980. In 1972, no significant differences in bass standing crop were found between the treated and non-treated regions.

Orange Lake

Fish total standing crop (numbers) and biomass were related to hydrilla levels (Table 48). Maximal values occurred in peak hydrilla years with fewest fish collected when hydrilla was not present. Standing crop ranged from 102,680 individuals/ha in 1977 to 4,187 individuals/ha in 1978. Biomass was also greatest in 1977 439.7 kg fish/ha. Fewest fish were collected in 1980 at (130.8 kg/ha). Although standing crpo and biomass values were much higher when large amounts of hydrilla were present, mean fish size was small (4 g). Maximum average fish weight occurred in 1978 (41 g) after a severe decline in hydrilla. The high numbers of small fish during peak hydrilla periods was due to large populations of small vegetation dwelling species.

The greatest number of fish species (30) was collected in Orange Lake during 1977 when hydrilla levels were greatest. Minimal numbers (18) were collected in 1978. Differences in species numbers were due primarily to non-collection of individual species that are usually infrequently collected (Group B fish). Bluespotted sunfish and golden topminnows, however, were the only species that had large populations during years in which hydrilla was present, but underwent dramatic declines beginning in 1978 and were not collected when hydrilla was not present.

Dominant forage fish populations underwent distinct changes as hydrilla levels fluctuated within Orange Lake. During peak hydrilla infestation small bluegill, bluespotted sunfish, golden shiners and bluefin killifish were dominant. Taillight shiners and young bluegill became the dominant forage fishes in 1978 and 1979 when hydrilla coverage was lowest.

Gizzard shad, threadfin shad and taillight shiners, species usually associated with open water, underwent population reductions as hydrilla levels increased. Golden shiners, lake chubsuckers, golden topminnows, bluefin and

Table 48. Number and weight of fish collected in Orange Lake.

Species	Number (/ha)					Weight (kg/ha)				
	1977	1978	1979	1980	1981	1977	1978	1979	1980	1981
Florida gar	61	4	50	9	6	28	1.7	25.0	4.2	3
Bowfin	4	2	3	5	0	6.0	5.1	7.0	5.1	0
Gizzard shad	61	405	437	55	183	3.4	22.0	1.1	11.9	10.0
Threadfin shad	0	0	255	1855	1473	0	0	.5	3.0	2
Redfin pickerel	2	0	0	2	0	73.4	0	0	.1	0
Chain pickerel	117	24	32	27	102	22.0	14	26.4	12.4	23.0
Golden shiner	10505	65	1215	1437	8521	39.0	4.0	14	8.9	38
Taillight shiner	406	1215	9092	1700	588	.3	.7	5.1	.6	.3
Lake chubsucker	302	8	20	68	138	28.0	5.1	5	12.5	12.3
Yellow bullhead	<1	0	0	0	0	.3	0	0	0	0
Brown bullhead	123	0	0	7	0	1.1	<.1	0	.9	<.1
Tadpole madtom	<1	2	12	0	0	<.1	<.1	<.1	0	0
American eel	3	0	0	0	0	2.0	0	0	0	0
Golden topminnow	1551	0	0	481	42	1.2	0	0	.3	<1
Seminole killifish	<1	0	<1	4	0	<.1	0	<.1	<.1	0
Flagfish	10	0	0	2	0	<.1	0	0	<.1	0
Bluefin killifish	15379	34	450	378	4675	3.1	<.1	.2	.4	.8
Mosquitofish	6513	9	2	177	36	2.0	<.1	<.1	.2	<.1
Least killifish	1211	10	<1	10	4	<.1	<.1	0	<.1	<.1
Sailfin molly	279	0	0	4	0	.2	0	0	<.1	0
Brook silversides	457	34	108	11	615	.3	<.1	.1	<.1	.3
Pirate perch	5	0	0	0	0	<.1	0	0	0	0
Pygmy sunfish	15	0	0	0	2	<.1	0	0	0	<.1
Bluespotted sunfish	12029	0	2615	2251	25859	13.4	0	1.4	1.6	14.0
Warmouth	15235	327	564	281	713	62.1	.91	7.7	6.3	6.9
Bluegill	17874	937	3682	1074	12660	72.0	46.0	47.4	35.1	44.0
Dollar sunfish	286	0	0	0	142	.7	<.1	0	<.1	.2
Redear	12766	260	2166	1048	2424	36.4	36.0	25.1	14.8	8.0
Spotted sunfish	0	0	<1	0	0	0	0	<.1	0	0
Largemouth bass	469	47	70	82	123	21	30.1	3.5	8.5	11.2
Black crappie	4440	615	2088	140	1072	12.3	4.1	16.6	3.3	16.2
Swampdarter	2574	189	284	29	309	.9	<.1	.1	<.1	.1
Total	102680	4187	23148	11137	59685	439.7	170.5	186.7	130.8	190.8

least killifishes, brook silversides and bluespotted sunfish had maximum standing crops when hydrilla was the dominant vegetation within Orange Lake.

Threadfin shad were not collected during 1977 and 1978. The lack of threadfins in 1978 was probably due to their near elimination within Orange Lake in 1977 when hydrilla coverage exceeded 90%. Threadfins were collected initially in 1979, but by 1981 when hydrilla was reinfesting the open water regions of the lake, population levels began to decline. The high coverage of hydrilla prevented threadfin shad from foraging due to the elimination of the limnetic habitat. Baker et al. (1971) reported that threadfin shad were limnetic feeders, consuming zooplankton within the open water areas of the lake. This might explain the reduction of threadfins in 1977 and the trend toward decreasing standing crop in 1981.

Golden shiners, lake chubsuckers, golden topminnows, bluefin and least killifish, brook silversides and bluespotted sunfishes had maximum standing crop levels when hydrilla was dominant within Orange Lake.

Juvenile Sportfish

Juvenile chain pickerel were collected in significantly greater numbers per hectare in 1977 and 1981 (Table 49). Average individual weights, however, were significantly greater in 1978 when hydrilla coverage was minimal and lowest in 1979 when hydrilla was beginning to expand into the littoral area. Small warmouth densities and biomass were significantly greater during 1977 (Table 49), but average weights were greatest during years of least hydrilla coverage (Table 50). Juvenile bluegills attained maximum densities in 1977 and 1981 when hydrilla coverage was greatest (Table 49). Average fish weights, however, were greatest in 1979 and 1980 when hydrilla was expanding into the littoral area but coverage did not exceed 30%. Juvenile redear numbers and biomass were significantly greater in

Table 49. Weighted mean number per hectare and kilograms per hectare of juvenile sportfish in Orange Lake. (Values in a column followed by the same letter have overlapping 90% confidence intervals.)

Year	Chain pickerel		Warmouth		Bluegill		Redear		Largemouth bass		Black crappie	
	#ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha
1977	91^{A}	8.7^{A}	15104^{A}	45.9^{A}	17672^{A}	44.2^{A}	12700^{A}	22.3^{A}	435^{A}	7.0^{A}	4420^{A}	6.6^{A}
1978	8^{B}	2.2^{BC}	324^{C}	$.5^{C}$	4782^{B}	11.7^{BC}	101^{C}	2.7^{B}	4^{C}	0.1^{C}	612^{B}	3.4^{A}
1979	1^{B}	0.1^{D}	538^{BC}	2.4^{BC}	3627^{B}	33.4^{ABC}	2092^{B}	6.2^{B}	68^{B}	2.2^{B}	2078^{A}	11.8^{A}
1980	11^{B}	0.4^{CD}	265^{B}	3.5^{BC}	914^{B}	8.2^{C}	1012^{B}	6.7^{B}	72^{B}	2.2^{B}	138^{B}	2.0^{A}
1981	73^{A}	6.7^{AB}	681^{B}	4.1^{B}	12601^{A}	34.9^{AB}	2403^{B}	5.8^{B}	100^{AB}	3.0^{B}	1047^{AB}	7.9^{A}

1977 (Table 49), but average weights were significantly greater in 1978 (Table 50). During other years, average weights were very similar. Greater numbers and biomass of juvenile largemouth bass were collected during 1977 and 1981 when hydrilla densities were greatest (Table 49). Average weights, however, were not statistically different for any of the years (Table 50). Juvenile black crappie densities did not appear to be related to the amount of hydrilla as greatest numbers occurred in 1977, 1979 and 1981 years in which hydrilla coverage ranged from 17 to 95% (Table 49). Mean weights were not significantly different for any of the years (Table 50).

Harvestable Sportfish

Numbers and biomass of harvestable chain pickerel were not significantly different for any of the study years (Table 51). Average weights were significantly greater in 1978, 1979, and 1980 when hydrilla cover was less than 22%. Average weights were greatest during 1978 when hydrilla coverage was lowest and continually decreased as the amount of hydrilla increased.

Warmouth numbers and biomass were maximal during 1977 (Table 51). Average weight, however, was lowest during 1977 (Table 50). Warmouth attained greatest size (weight) during 1979 and 1980 when hydrilla coverage was moderate.

Creel-size bluegill reached maximum densities and biomass values in 1977, 1978 and 1980, but total numbers were significantly reduced in 1979 and 1981 compared to 1977, the maximum hydrilla year. Average weight of bluegills was significantly greater during years when hydrilla coverage was less than 20%.

Redear numbers and biomass values were greatest in 1978, but declined through 1981 (Table 51). Redear were largest during the years (1979 and 1980) when hydrilla was expanding into the profundal region. Weights decreased as hydrilla exceeded 28% coverage (Table 50).

Table 50. Average weight (grams) of harvestable (H) and juvenile (SH) sportfish in Orange Lake (Values in a column followed by the same letter are not significantly different at P <.1).

Year	Chain pickerel		Warmouth		Bluegill		Redear		Largemouth bass		Black crappie	
	SH	H	SH	H	SH	H	SH	H	SH	H	SH	H
1977	108^{B}	453^{B}	8^{A}	114^{C}	7^{BC}	133^{C}	7^{B}	135^{C}	27^{A}	375^{C}	3^{B}	288^{A}
1978	387^{A}	919^{A}	6^{A}	151^{ABC}	3^{C}	200^{A}	39^{A}	189^{B}	24^{A}	815^{A}	15^{AB}	438^{A}
1979	70^{BC}	859^{A}	7^{A}	173^{A}	11^{AB}	219^{A}	4^{B}	243^{A}	37^{A}	668^{AB}	9^{B}	367^{A}
1980	46^{C}	783^{A}	15^{A}	168^{AB}	13^{A}	168^{B}	7^{B}	212^{AB}	34^{A}	495^{BC}	13^{AB}	439^{A}
1981	103^{B}	506^{B}	14^{A}	128^{BC}	8^{BC}	155^{BC}	7^{B}	84^{D}	40^{A}	354^{C}	23^{A}	328^{A}

Table 51. Weighted mean number per hectare and kilograms per hectare of havestable sportfish in Orange Lake. (Values in a column followed by the same letter have equivalent 90% confidence intervals).

Year	Chain pickerel		Warmouth		Bluegill		Redear		Largemouth bass		Black crappie	
	#/ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha	#/ha	kg/ha
1977	26^{A}	13.4^{A}	131^{A}	16.3^{A}	202^{A}	27.8^{A}	97^{AB}	14.2^{A}	34^{A}	13.8^{A}	20^{A}	5.8^{AB}
1978	16^{A}	11.5^{A}	3^{B}	$.4^{B}$	155^{AB}	33.9^{AB}	159^{A}	33.3^{A}	43^{AB}	30.0^{AB}	2^{B}	$.8^{B}$
1979	31^{A}	26.4^{A}	26^{B}	5.3^{AB}	56^{B}	14.0^{AB}	74^{ABC}	18.9^{AB}	2^{B}	1.3^{B}	10^{A}	4.8^{AB}
1980	16^{A}	12.0^{A}	16^{B}	2.9^{B}	160^{AB}	26.9^{A}	36^{BC}	8.1^{AB}	10^{AB}	6.3^{AB}	3^{B}	1.3^{AB}
1981	30^{A}	16.0^{A}	32^{B}	2.7^{B}	60^{B}	9.0^{B}	21^{C}	1.9^{B}	22^{AB}	8.2^{AB}	26^{A}	8.3^{A}

Largemouth bass numbers and biomass differences were significant only between 1977 and 1979, with lowest standing crop and biomass in 1979. Greatest numbers and weights, occurred during 1978 when hydrilla coverage was lowest. The average size of largemouth bass was significantly reduced in 1977 and 1981 when hydrilla exceeded 59 and 28% coverage, respectively.

Harvestable black crappie underwent fluctuations similar to that of the juveniles. Maximum densities occurred on a repetitive two year basis with no significant annual biomass differences.

Fish habitat relationships. Chain pickerel were collected only from vegetated habitats except in 1978 when some were collected from the pelagic area. In 1977, pickerel were collected only in hydrilla and spatterdock habitats. Spatterdock, however, also contained hydrilla. Young-of-year (YOY) pickerel biomass was greatest in 1977 and YOY were not represented in the 1978 and 1979 collections but were collected in 1980 and 1981 when hydrilla coverage was increasing. Fish <32 cm were almost always found in either hydrilla or spatterdock and seemed to prefer hydrilla when hydrilla was present. In 1978, 1979 and 1980, most of the biomass was represented in the larger size classes (Figure 90), whereas in peak hydrilla years (1977 and 1981) biomass was shifted toward smaller fish.

Black crappie were collected from all habitats. Small YOY crappie preferred vegetated habitats and only in 1979 were YOY crappie collected in appreciable amounts from open water. Our samples also suggest that adult black crappie utilize vegetation habitats to a considerable extent. These data, however, might be misleading as the open water crappie populations were not adequately sampled. Subsequent otter trawling indicates that adult black crappie inhabit the deeper open water areas of Orange Lake (Maceina, personal communication).

Largemouth bass, like crappie, were collected from all habitats. Greater weights of bass were collected in 1977 and 1978. Maidencane, although it occupies only about 5% of the lake surface, was utilized as a habitat in 1979 by bass greater than 32 cm. In 1978, after hydrilla declined, spatterdock and open water were the only habitats utilized. Spatterdock was the preferred habitat in all years with hydrilla of secondary importance while hydrilla was expanding. YOY bass were not collected in 1978, but were collected in all other years from both hydrilla and spatterdock communities. In 1977, when hydrilla occupied 59% of the lake and was surface matted over this entire area, it was not utilized by bass greater than 28 cm. In years (1980, 1981) when hydrilla was present, but not surface matted over wide expanses, it was utilized as a habitat by largemouth bass. In these years, hydrilla was interspersed with open water. Open water was utilized by bass during years when hydrilla coverage was minimal (Figure 90). It should be noted, however, that during 1978 and 1979 much of the lake was occupied by open water, which indicates that existing vegetated habitats were important.

The mean number and biomass of warmouth was greatest in 1977, with the greater biomass occurring in the smaller size groups (Figure 91). Warmouth biomass declined drastically from 1977 to 1978 and then increased through 1981 but did not reach 1977 levels. Hydrilla and spatterdock communities were inhabitated almost equally by warmouth during 1977. In 1978, after the hydrilla decline, spatterdock, open water and maidencane communities were important. Maidencane communities were especially important considering that maidencane occupied only 5% of the total lake coverage. In 1979, 1980 and 1981, warmouth were collected primarily from spatterdock but as hydrilla coverage increased, greater biomass occurred in the hydrilla habitats.

Bluegill populations in 1977 were characterized by high numbers and biomass in the small size classes; collections

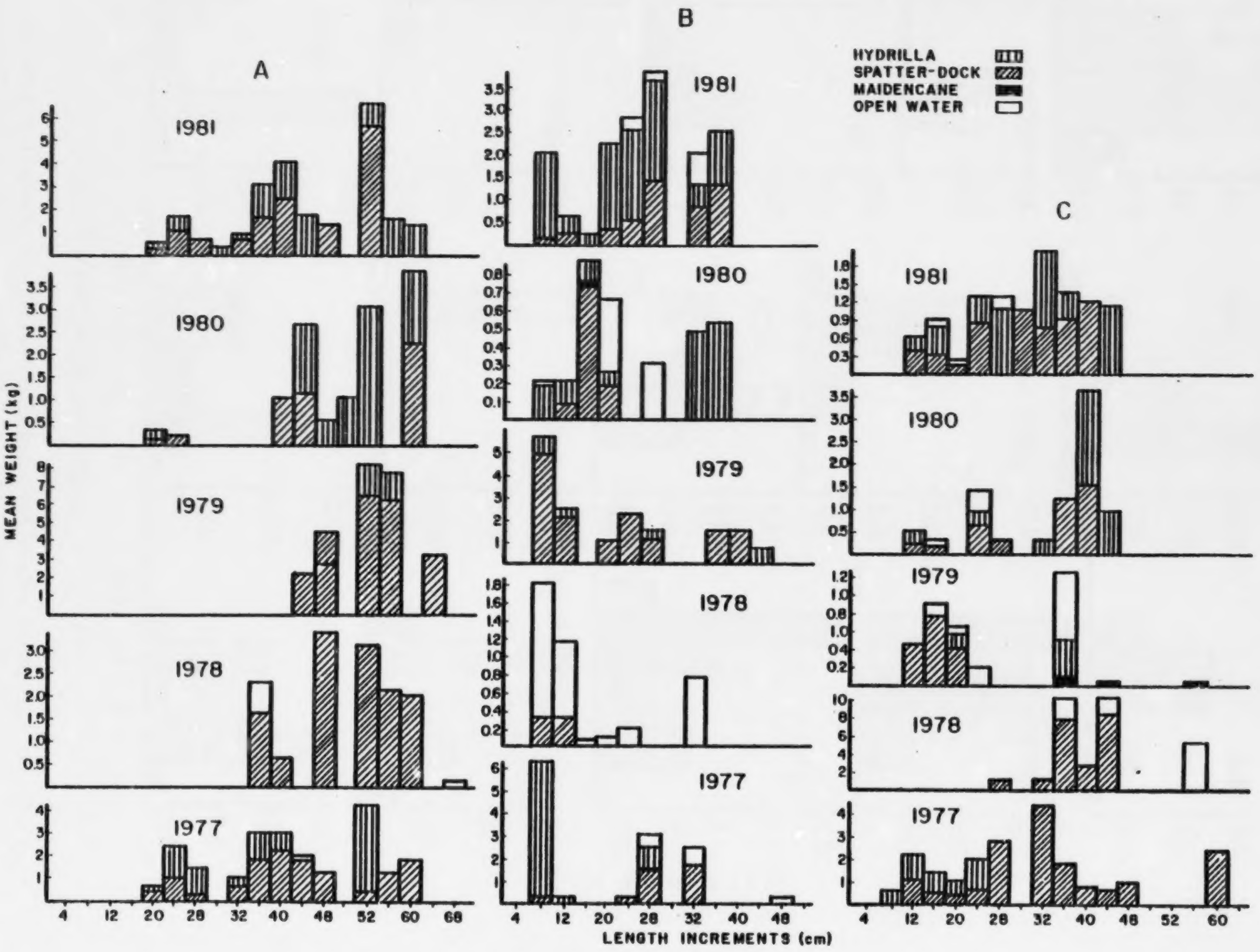


Figure 90. Mean weight histograms according to vegetation type for chain pickerel (A), black crappie (B), and largemouth bass (C) collected from Orange Lake.

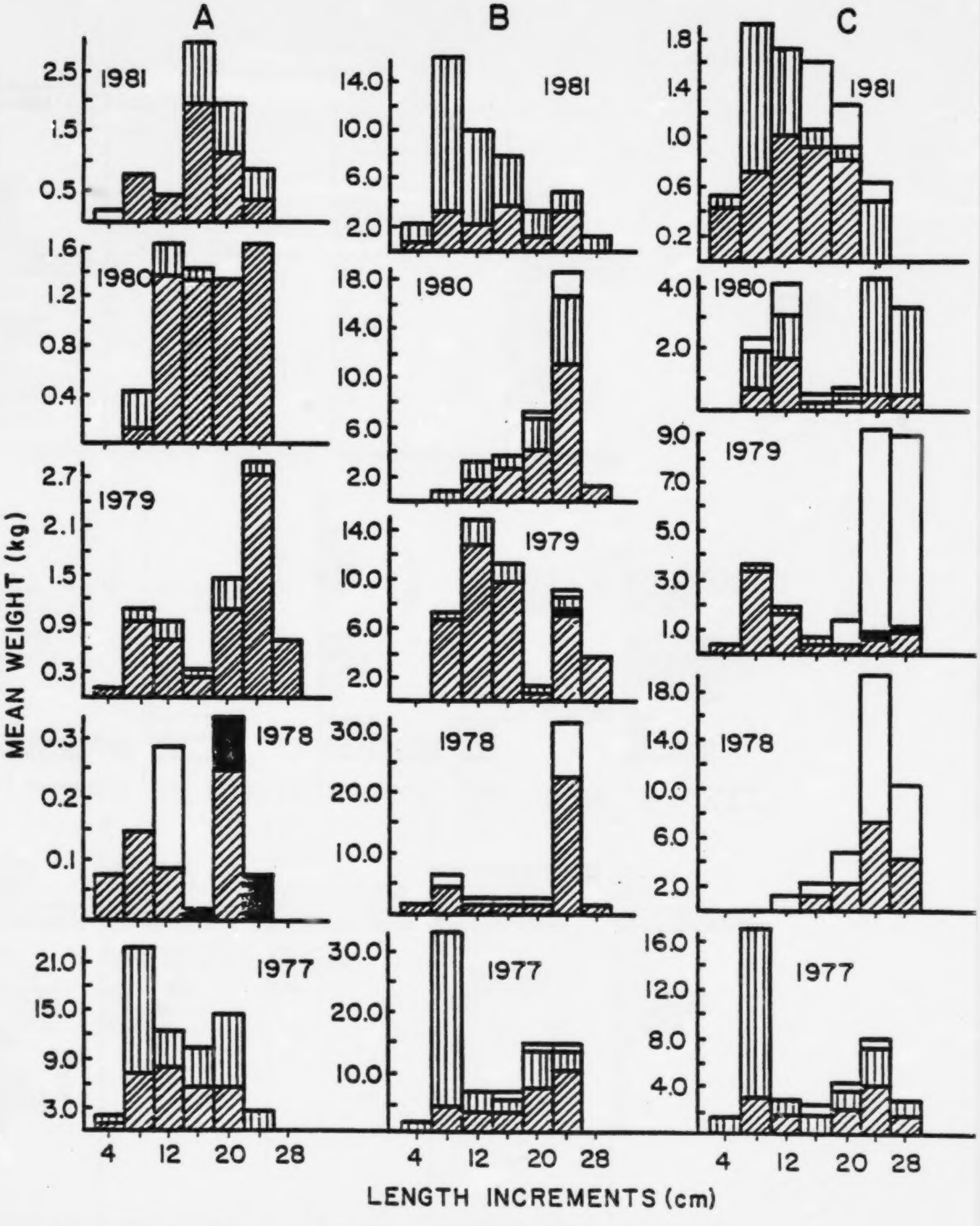


Figure 91. Mean weight histograms according to vegetation type for warmouth (A), bluegill (B), and redear (C) collected from Orange Lake.

came primarily from hydrilla habitats (Figure 91). As hydrilla disappeared in 1978, a shift in habitat and biomass distribution occurred. Small bluegills were collected less frequently in 1978 and only from spatterdock and open water. These habitats were almost equally represented in the lake. Greatest bluegill biomass occurred in the 24 cm size class. Total biomass (1979) was similar to the preceding year, but biomass was represented in smaller size classes indicating greater survival and/or more successful spawning during Spring 1979. Greater spawning success might be indicated if biomass distributions are compared to 1980. Even though hydrilla coverage was greater in 1980, fewer small fish were collected indicating that spawning was probably not as successful as the previous year. Greater biomass in 1980 occurred in the larger size classes which were collected primarily from spatterdock and hydrilla. By 1981, hydrilla was again becoming an important bluegill habitat. YOY bluegills were abundant with the majority of the biomass contained in size classes less than 20 cm.

Redear distribution followed a trend similar to bluegills. Greatest total biomass occurred in 1977 and declined steadily through 1981. In peak hydrilla years (1977 and 1981), greater biomass was represented in the smaller size classes. In 1978, YOY fish were poorly represented, however, the greatest biomass in fish of harvestable size occurred in 1978. Redears were collected only from spatterdock and open water during 1978 (Figure 91). Redears >20 cm in 1979 were collected primarily from open water areas whereas smaller fish were collected from spatterdock. Hydrilla was of increasing importance in 1980 and 1981.

Considerable amounts of data are available pertaining to the relationship between sportfish populations and native aquatic macrophytes. Bailey (1978) reported that total fish standing crop, shad biomass, numbers of harvestable sportfish and young-of-year sportfish did not change in

Arkansas lakes when grass carp were used to remove aquatic vegetation. Plant removal resulted in improved condition factors of largemouth bass, bluegill, and redear sunfish. Infestation by Eurasian watermilfoil (*Myriophyllum spicatum*) in Currituck Sound, North Carolina, caused increases in both total fish weight and number per hectare with decreased average weight per individual. Ictalurids and centrarchids exhibited increases in total weights and numbers. Young-of-year and older largemouth bass numbers were not significantly different between pre- and post-watermilfoil samples (Borawa et al. 1978). Wegener and Williams (1974) stimulated development of aquatic vegetation in Lake Tohopekaliga with an extreme drawdown. The increase in native aquatic plants and subsequent macroinvertebrate production resulted in a doubling of sportfish biomass. Cope et al. (1969) and Cope et al. (1970) found bluegill and redear in Oklahoma ponds grew faster when submersed vegetation was controlled. Ricker (1942) reported no associations between bluegill growth rates and abundance of aquatic vegetation in a series of Indiana ponds. Florida largemouth bass spawning was suppressed in hatchery ponds when all native aquatic vegetation was removed (Smith and Crumpton 1977). Buck and Thoit (1970) attributed delayed bass spawning to dense vegetation mats which caused elevated pH (10.2). These fish spawned after the vegetation was removed and the pH reduced.

Hydrilla, because of its ability to occupy the limnetic area of lakes, poses new problems. Open water feeding and spawning areas are no longer available which places constraints on fish populations. Very little published information is available concerning the influence of hydrilla infestations on sportfish populations. Colle and Shireman (1980) found condition factors of largemouth bass, bluegill and redear underwent dramatic reductions as hydrilla became more abundant in two Florida lakes. Harvestable largemouth bass had low condition factors when coverage exceeded 30% while juvenile bass were not affected until levels were greater than 50%. Bluegill and redear condition was not reduced until coverage reached 80%. Data from Lake Pearl indicates that harvestable largemouth bass growth rates were near maintenance conditions when hydrilla coverage was greater than 60% for a three-year period. The detrimental effects on sportfish populations caused by hydrilla is probably due to its growth form. As indicated in this study, bass avoid hydrilla when it is present in dense mats. Hydrilla utilizes light more efficiently than native submersed plants which allows it to grow rapidly, forming dense mats in deeper water than native macrophytes; with dense surface mats being present for at least six months each year. This habitat provides a haven for juvenile sportfish due to a combination of increased invertebrate forage and protection from predation, which leads to stunted populations.

The number of juvenile sportfish in Orange Lake was greatly elevated in 1977 compared to the other study years. The amount of hydrilla, however, during 1976 and 1977 exceeded 47% coverage in the open water areas whereas during the period from 1978 through 1981 coverage did not exceed 30%. Savino and Stein (1982) demonstrated, in experimental situations, that vegetation is effective as cover for reducing predation of juvenile bluegills. They found that protection for dispersed bluegills was not reached until stem densities reached 40% cover. Vegetation cover, therefore, might explain the differences in population density of juvenile sportfish among years. As hydrilla continues to spread, creel-sized fish are unable to forage effectively, their growth declines and the number of forage species increases. Eventually, stunted populations result resembling the stunted fish population syndrome described by Swingle (1950). Subharvestable bluegills in Orange Lake showed this trend in both 1977 and 1981; both years were characterized by extremely large populations consisting of small to intermediate fish. The standing crops of the primary predators, bass and pickerel, were equivalent or larger than in other years. This suggests that the increase in bluegill numbers was not due to a decrease in predator populations but to the physical constraint of efficient foraging by both predatory species.

Largemouth bass population structure is also greatly altered in hydrilla dominated systems. Although subharvestable numbers are quite large in hydrilla lakes, the growth characteristics of the individuals are extremely slow. In Lake Pearl, first year growth was 150 mm when hydrilla coverage was in excess of 60%. Further growth reduction occurred after the first year, thus a minimum of three years was required for bass to reach harvestable size. The large population of subadult bass present in 1977 and 1981 in Orange Lake is also indicative of this trend. This retarded growth is not caused by an inadequate forage base, but an unavailable prey population due to the physical limitation created by hydrilla.

The small standing crop of subharvestable bass present in Orange Lake in 1978 (4/ha) was not due to poor nesting success, but to predation upon the young-of-year fish by bass and pickerel when hydrilla underwent a dramatic decline in early summer. Blocknets set in May 1978 with the Florida Game and Fresh Water Fish Commission contained approximately 125 subharvestable bass per hectare but by November when nets were reset only 4/ha were collected. This trend of extreme year class reduction concurrent with the first year of hydrilla removal has also occurred in Lake Baldwin, Florida. In all systems (Lake Baldwin, Lake Pearl and Orange Lake), nesting fish and fry schools were present, but by the fall, survival was extremely low. We feel this year class failure is due to predation by the large population of slow growing intermediate bass that had been associated with the dense hydrilla. In both Orange Lake and Lake Baldwin, spawning in subsequent years produced normal year classes.

The relatively short life cycles and rapid growth of warmwater sportfish allows these populations to recover rapidly when hydrilla levels decrease as evidenced by the 1978 through 1980 fish collections from Orange Lake. The decrease in hydrilla was followed by a concomitant increase in the average weight of sportfish. It is generally accepted by Florida fish biologists that native aquatic vegetation is beneficial to sportfish populations. Hydrilla, however, can be detrimental to sportfish (Colle and Shireman 1980) and should be managed so maximum coverage does not exceed 30% of the lake surface. If a viable sportfish population is a management goal in hydrilla-infested lakes, some form of aquatic vegetation control will be mandatory. When hydrilla covers a substantial portion of the lake, increases in subharvestable sportfish populations will occur, however, condition factors and sportfish size decrease due to reduced foraging efficiency resulting in extremly slow growth.

Welaka Fish

Electrofishing samples were conducted in all research ponds in November 1982. Quantitative data were collected by electrofishing the perimeter of each pond and along two diagonals across the ponds. All fish collected were placed in aerated live wells, weighed, measured and returned to their respective ponds. Mean number of fish collected by species and size group (<150 mm and ≥ 150 mm for bluegill; < 250 mm and ≥ 250 mm for largemouth bass) was calculated for each treatment. Coefficient of condition for bass and bluegill were also determined by vegetation treatment and size group.

Bluegill coefficient of condition was significantly higher in the fertilization treatment for fish <150 mm (Figure 92). Harvestable bluegill did not follow this trend. Maximum condition in fish >150 mm occurred within the herbicide treatments in which 40% of the vegetation was controlled. Largemouth bass K(TL)'s revealed no relationship with vegetation levels or treatment methods, but sample size was small for almost all size groups and treatments (Figure 93).

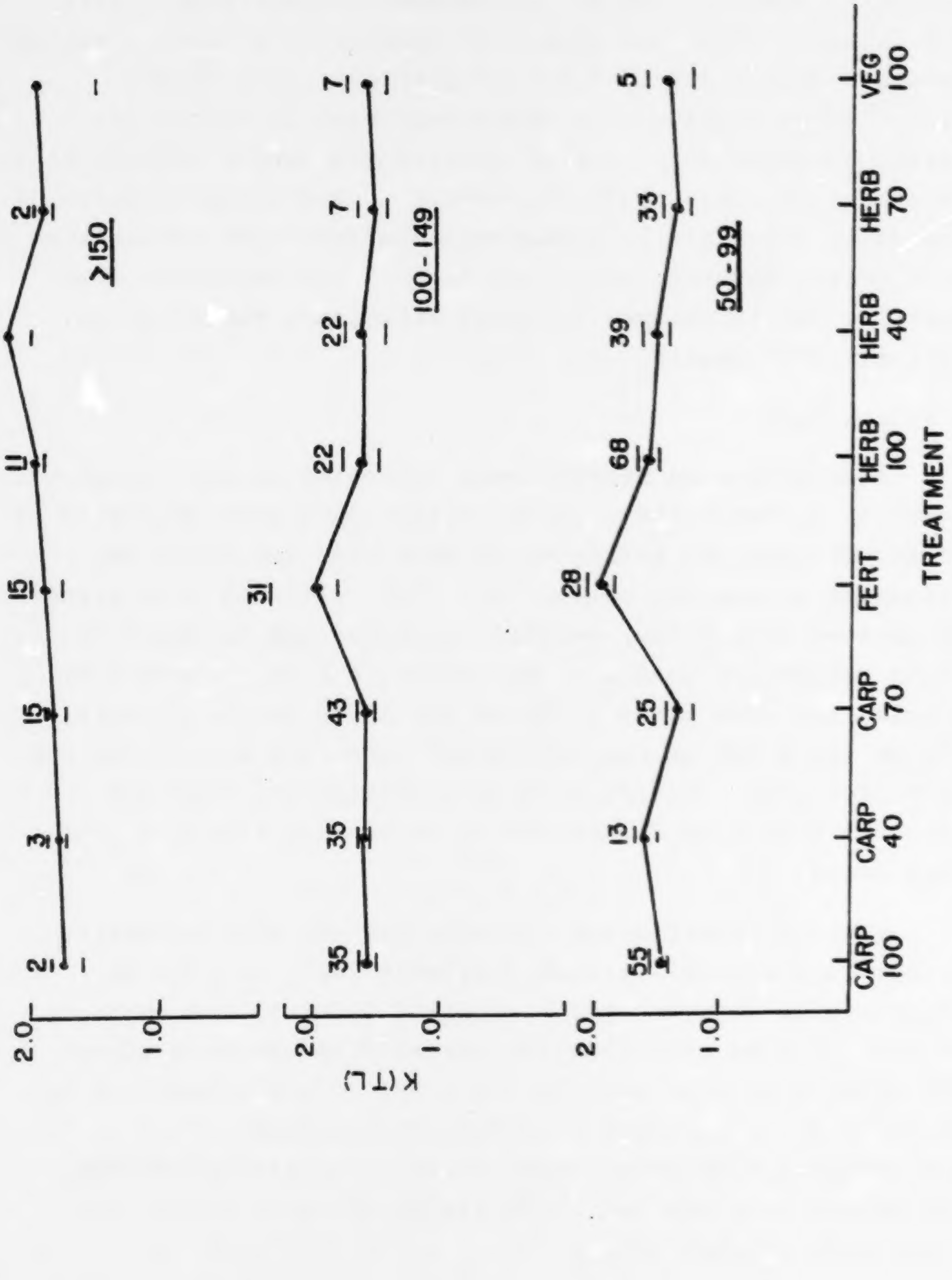


Figure 92. Coefficient of condition for bluegills collected from Welaka study ponds.

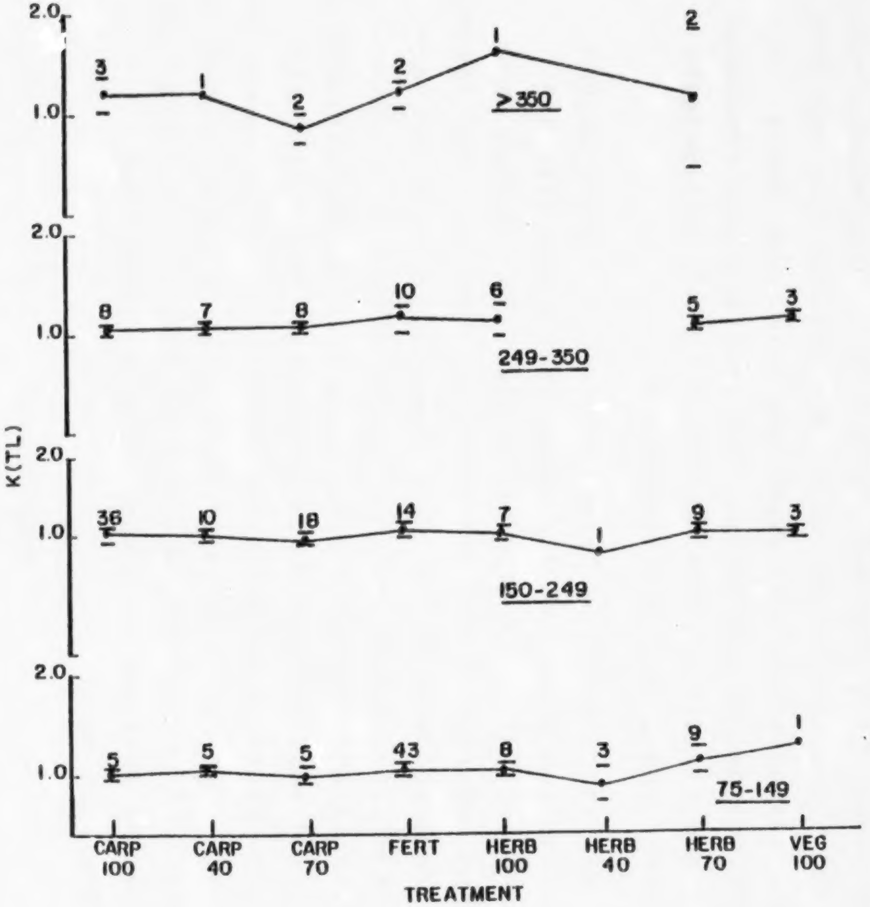


Figure 93. Coefficient of condition for largemouth bass collected from Welaka ponds.

Bluegill attained maximum densities in the two complete vegetation control treatments (Table 52). The 100% grass carp vegetation control ponds had a mean of 132 bluegill and the 100% herbicide control ponds had a mean of 146 bluegills. The ponds that received no aquatic macrophyte control (vegetation 100%) had the lowest number of bluegill collected (7). The large reduction in bluegill numbers was due to summer kills from oxygen depeletion that occurred in these ponds. The intermediate levels of vegetation control, (30 and 60% removal) had larger populations than the 100% vegetation coverage, but were much lower than total vegetation management ponds. The fertilization treatment had a greater number of bluegills than the intermediate herbicide and grass carp treatments.

Maximal numbers of largemouth bass occurred in the fertilization ponds and the ponds that grass carp had removed 100% of the vegetation (Table 52). Lowest bass density occurred in the 30% herbicide ponds. Total removal of vegetation with herbicides, however, did not increase bass numbers. Final analysis of the effect of different aquatic plant management strategies on fish density will be conducted when all ponds are drained in 1984. The extra time is needed to determine if vegetation levels impact fish population in pond systems. When all ponds are drained, all fish will be collected, weighed and measured, allowing the data to be analyzed on actual numbers rather than catch/effort data.

Food Habits

Lake Pearl

Largemouth bass in Lake Pearl underwent distinct changes in food habits with increasing size. Freshwater shrimp, aquatic insect adults and larvae, and small fish were the primary components of their diets (Table 53). Bass 75-150 mm were the only size group in which aquatic insects made up an appreciable percentage of the diet. Mayflies, damselflies and dragonflies comprised the majority of the

Table 52. Mean number of bluegill and largemouth bass collected in the Welaka ponds.

Treatment	Bluegill			Largemouth bass		
	<150	≥150	Total	<250	≥250	Total
Carp 100	126	6	132	17	4	21
Carp 30	36	4	40	8	5	13
Carp 60	54	5	59	8	6	14
Fertilization	56	7	63	20	4	24
Herb 100	143	4	147	5	2	7
Herb 30	29	2	31	1	1	2
Herb 60	41	1	42	11	4	15
Veg 100	6	1	7	3	2	5

Table 53. Percent first ranking of major food items of largemouth bass in Lake Pearl, Florida.

Year	1979				1980				1981				1982			
Number examined	72	83	122	58	104	104	151	30	108	108	166	59	80	80	101	70
Number with food	38	45	72	31	66	66	96	13	74	74	72	24	48	48	39	37
Size Group	75-150	151-250	251-350	>350	75-150	151-250	251-350	>350	75-150	151-250	251-350	>350	75-150	151-250	251-350	>350
Shrimp and crawfish	45	16	35	16	16	17	17	3	35	8	7	4	48	37	10	0
Insects	8	4	3	3	26	4	2	0	31	12	0	0	15	6	5	0
Fish[a]	47	80	62	81	58	79	81	97	34	80	93	96	38	57	85	100
Centrarchids	50	13	43	73	9	21	48	43	17	39	71	51	2	42	12	93
Vegetation dwelling species	50	87	57	27	91	79	52	57	83	61	29	43	98	58	88	7

insects consumed. Bass had already grown out of the zooplankton feeding stage by 75 mm, for only one collected individual contained cladocerans. Mean length of prey consumed ranged from 26 to 45 mm; indicative of consumption of young-of-year centrarchids or small vegetated dwelling fishes. Small vegetation dwelling fish made up over 83% of the fishes consumed in all study years except 1979 (Table 54). Percent empty stomachs ranged from 52 to 68%. No chronological changes occurred through the years with respect to type or quantity of forage consumed.

Fish 151-250 mm underwent a change in food habits (Table 55). The elimination of vegetation in 1982 caused a shift from fish to shrimp consumption. Prior to 1981, fish made up 80% of the first ranking occurrence within this size group. The switch to shrimp in 1982 was due to an insufficient number of fish of adequate forage size for this size class. Examination of mean length of fish consumed revealed this size group utilized forage fish that were approximately 40 mm. When hydrilla was removed from Lake Pearl in 1982, there was a large reduction in the standing crop of centrarchids <100 mm and small vegetation dwelling fishes. The population of this size group (3,137 individuals) was extremely large. Dense hydrilla eliminated predation on young bass by larger predators and also caused an increase in small forage fishes, thus survival of this size group was enhanced. By 1981, consumption of vegetation dwelling fishes decreased and shifted to young centrarchids. This shift was caused by a decrease in vegetated habitat in 1981 and total submersed vegetation elimination by 1982. The lack of adquate size forage for this size group resulted in a reduction in growth rates. The number of bass in this size group, however, should decrease and stabilize at a lower standing crop, allowing the establishment of an adequate forage base. The stunted fish populations caused by hydrilla will take at least two years to recover. Harvestable fish (251-350 mm) also revealed a chronological shift in food habits due to vegetation elimination. Fish

Table 54. Percent occurrence (%O) and percent first ranking (%1st) of food items for 75-150 mm largemouth bass in Lake Pearl, Florida.

Year	1979		1980		1981		1982	
Number examined	72		104		108		80	
Number w̄ food	38		66		74		48	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Cladocera								
Sida			1.5	1.5				
Decapoda								
Palaemonetes	44.7	44.7	19.7	15.2	40.5	35.1	47.9	47.9
Araneae	2.6	2.6						
Ephemeroptera								
Callibaetis (larvae)	2.6	0			9.5	8.1		
Caenis (larvae)					9.5	8.1		
Odonata								
Erythemis simplicolis (adults)			1.5	1.5	1.4	1.4		
Celithemis (larvae)			1.5	1.5				
Libellulidae (larvae)			9.1	4.5	2.7	1.4		
Libellulidae (adults)			3.0	3.0	1.4	1.4		
Coenagrionidae (larvae)	2.6	0	1.5	1.5				
Coenagrionidae (adults)					1.4	1.4		
Unidentified (larvae)							4.2	4.2
Unidentified (adults)					4.0	4.0	2.1	2.1
Diptera								
Tendipedidae (larvae)			3.0	0			2.1	2.1
Tendipedidae (pupae)	7.9	2.6	9.1	7.6	13.5	8.1		
Ceratopogonidae (larvae)			1.5	0				
Hemiptera								
Corixidae	15.8	2.6					2.1	2.1
Gerridae			4.5	4.5			2.1	2.1
Insecta unidentified			1.5	1.5			2.1	2.1

Table 54. Continued.

Year	1979		1980		1981		1982	
Number examined	72		104		108		80	
Number w̄ food	38		66		74		48	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Osteichthyes								
Ictalurus nebulosus			1.5	1.5				
Fundulus chrysotus			9.1	9.1	5.4	5.4	10.4	10.4
Gambusia affinis			12.1	12.1	5.4	5.4		
Lucania goodei					1.4	1.4		
Labidesthes sicculus			16.7	16.7				
Enneacanthus gloriosus	2.6	2.6	1.5	1.5	1.4	1.4		
Lepomis gulosus	2.6	2.6						
Lepomis macrochirus			3.0	3.0	1.4	1.4	2.1	2.1
Lepomis sp.			1.5	0				
Micropterus salmoides	2.6	2.6	1.5	1.5	1.5	1.5		
Heterandia formosa	5.3	2.6			2.7	0		
Etheostoma fusiforme			10.6	6.1			6.2	6.2
Unidentified	36.8	36.8	6.1	6.1	20.3	17.6	18.8	18.8

Table 55. Percent occurrence (%O) and percent first ranking (%1st) of food items from 151-250 mm largemouth bass in Lake Pearl, Florida.

Year	1979		1980		1981		1982	
Number examined	83		135		155		147	
Number $\bar{w}$ food	45		81		50		81	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Decapoda								
Palaemonetes	26.7	15.6	18.5	14.8	10.0	8.0	37.0	34.6
Astacidae	2.2	0	2.5	2.5			2.5	2.5
Araneae							2.5	0
Ephemeroptera								
Callibaetis (larvae)	2.2	2.2						
Odonata								
Erythemis simplicolis (larvae)							1.2	0
Aeschnidae (larvae)							1.2	0
Libellulidae (larvae)					2.0	0		
Libellulidae (adults)	2.2	0						
Coenagrionidae (larvae)					2.0	0		
Coenagrionidae (adults)	6.7	0	1.2	1.2	4.0	4.0	1.2	0
Unidentified (adults)	2.2	2.2	1.2	1.2			1.2	1.2
Diptera								
Tendipedidae (larvae)	2.2	0						
Tendipedidae (pupae)	4.4	0						
Trichoptera								
Orthotrichia					4.0	2.0		
Hemiptera								
Belastoma							1.2	1.2
Corixidae	4.4	0					1.2	1.2
Gerridae					4.0	4.0	1.2	0
Notonectidae					2.0	0		
Unidentified							1.2	0
Orthoptera								
Acrididae							1.2	1.2

Table 55.Continued.

Year	1979		1980		1981		1982	
Number examined	83		135		155		147	
Number w̄ food	45		81		50		81	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Insecta unidentified							1.2	1.2
Reptilia								
Seminatrix pygaea					2.0	2.0		
Osteichthyes								
Notemigonus chrysoleucas	4.4	4.4						
Ictalurus nebulosus	2.2	2.2						
Fundulus chrysotus	11.1	11.1	11.1	9.9	6.0	6.0	11.1	8.6
Gambusia affinis	2.2	2.2	7.4	7.4	4.0	2.0	4.9	2.5
Lucania goodei	6.7	2.2	2.5	2.5				
Labidesthes sicculus	2.2	2.2	8.6	7.4	4.0	4.0	2.5	2.5
Elassoma evergladei			1.2	1.2	2.0	2.0		
Ennecanthus gloriosus	22.2	20.0	4.9	4.9	8.0	8.0	4.9	4.9
Lepomis gulosus							1.2	1.2
Lepomis macrochirus			2.5	1.2	14.0	14.0	16.0	16.0
Lepomis sp.	4.4	4.4	8.6	7.4				
Micropterus salmoides	2.2	2.2					1.2	1.2
Heterandria formosa					4.0	0	2.5	2.5
Etheostoma fusiforme							4.9	4.9
Unidentified	35.6	28.9	38.3	37.0	44.0	44.0	12.3	12.3
Chlorophyta unidentified			2.5	0				
Angiospermae								
Hydrilla			1.2	1.2				

were the primary food in all study years, except 1979 when shrimp was the major dietary component. Centrarchids and vegetation dwelling fishes were consumed in equal proportions during 1979 and 1980 (Table 56). As submersed vegetation levels declined in 1981, a shift toward consumption of centrarchids occurred. Centrarchids avoided predation prior to 1981 because of hydrilla density. When all submersed vegetation was removed during 1982, this size group of fish switched from a forage base of centrarchids (>55 mm) to consumption of vegetation dwelling fishes.

The largest size group of bass (>350 mm) fed almost entirely on fish (Table 57). Submersed vegetation elimination in 1982 provided this size group with an extremely large population of adequate length forage fish, thus there was a significant increase in growth. Hydrilla prior to 1982 had prevented these fish from feeding on single large prey items such as bluegill and redear; therefore, smaller vegetation dwelling fishes were consumed. Examination of mean total length of prey consumed revealed a significant increase in forage fish length as vegetation was removed (Table 58). Food habit data for this size group explains the significant increase in growth that occurred during 1982. Hydrilla places a physical constraint on foraging efficiency and forces the fish to consume smaller prey, resulting in an over expenditure of energy and a reduction in growth.

Orange Lake

Chain pickerel exhibited distinct shifts in food habits as the size of the prey they consumed increased as they grow. Pickerel <400 mm consumed fish that were an average length of 50 to 60 mm. This smaller size group fed on a diet consisting of freshwater shrimp, young-of-year centrarchids and small fish associated with vegetation (Table 59). Pickerel >400 mm fed principally on adult gizzard shad, bluegill, chubsuckers, golden shiners and other fish larger than 100 mm (Table 60). A trend toward

Table 56. Percent occurrence (%O) and percent first ranking (%1st) of food items from 251-350 mm largemouth bass in Lake Pearl, Florida.

Year	1979		1980		1981		1982	
Number examined	122		151		166		101	
Number w̄ food	72		96		72		39	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Amphipoda					1.4	0		
Decapoda								
Palaemonetes	41.7	20.8	19.8	12.5	12.5	6.9	12.8	10.3
Astacidae	16.7	13.9	3.1	3.1			5.1	5.1
Ephemeroptera								
Unidentified larvae					1.4	0		
Odonata								
Aeschnidae (larvae)			1.0	1.0				
Libellulidae (larvae)	1.4	0	4.2	3.1				
Coenagrionidae (larvae)			3.1	2.1				
Coenagrionidae (adults)	1.4	0						
Unidentified (adults)	2.8	1.4					2.6	2.6
Diptera								
Tendipedidae (larvae)					1.4	0		
Tendipedidae (pupae)	1.4	0						
Hemiptera								
Belastoma			1.0	0				
Gerridae	1.4	1.4						
Insecta unidentified							2.6	2.6
Osteichthyes								
Notemigonus chrysoleucas	1.4	1.4			2.8	2.8	12.8	10.3
Fundulus chrysotus	16.7	13.9	16.7	10.4	1.4	1.4	10.3	7.7
Gambusia affinis			16.7	10.4	2.8	1.4	5.1	2.6
Lucania goodei	2.8	0	2.1	2.1				
Lapidesthes sicculus	4.2	4.2	4.2	3.1	4.2	2.8	5.1	5.1

Table 56. Continued.

Year	1979		1980		1981		1982	
Number examined	122		151		166		101	
Number $\bar{w}$ food	72		96		72		39	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Osteichthyes (continued)								
Elassoma evergladei	1.4	0						
Enneacanthus gloriosus	11.1	9.7	4.2	2.1	5.6	5.6	2.6	2.6
Lepomis gulosus	8.3	8.3						
Lepomis macrochirus	5.6	4.2	15.6	15.6	20.8	20.8	10.3	7.7
Lepomis marginatus					1.4	1.4		
Lepomis sp.	1.4	1.4	9.4	9.4	15.3	15.3		
Micropterus salmoides	5.6	5.6	1.0	1.0	1.4	1.4		
Pomoxis nigromaculatus					1.4	1.4	2.6	2.6
Heterandria formosa					2.8	0		
Esox americanus	1.4	1.4			1.4	1.4		
Etheastoma fusiforme	2.8	1.4					7.7	7.7
Unidentified	16.7	11.1	26.0	22.9	37.5	37.5	35.9	33.3
Chlorophyta unidentified			2.1	0				
Angiospermae								
Hydrilla			3.1	1.0				

Table 57. Percent occurrence (%O) and percent first ranking (%1st) of food items for >350 mm largemouth bass in Lake Pearl, Florida.

Year	1979		1980		1981		1982	
Number examined	58		30		59		70	
Number w̄ food	31		13		24		37	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Decapoda								
Palaemonetes	9.7	6.4	7.7	0	4.2	4.2		
Astacidae	9.7	9.7	7.7	7.7				
Araneae	6.4	3.2						
Amphipoda								
Rana grylia	3.2	3.2						
Osteichthyes								
Erimyzon sucetta			7.7	7.7	12.5	12.5	8.1	8.1
Notemigonus chrysoleucas	3.2	3.2	15.4	15.4	12.5	12.5	2.7	2.7
Ictalurus nebulosus	3.2	3.2						
Fundulus chrysotus			7.7	7.7				
Gambusia affinis			7.7	7.7				
Labidesthes sicculus					4.2	4.2		
Ennecanthus gloriosus	6.4	6.4			4.2	4.2		
Lepomis macrochirus	16.1	16.1			4.2	4.2	40.5	50.4
Lepomis microlophus			7.7	7.7				
Lepomis sp.	3.2	3.2	15.4	15.4				
Micropterus salmoides	3.2	3.2			4.2	4.2		
Pomoxis nigromaculatus	3.2	3.2			4.2	4.2		
Heterandria formosa					4.2	0		
Dorosoma cepedianum	3.2	3.2						
Unidentified	35.5	35.5	30.8	30.8	50.0	50.0	54.0	48.6

Table 58. Mean length of fish consumed by largemouth bass in Lake Pearl.

Year	Size Group			
	75-150	151-250	251-350	>350
1979	45	35	57	110
1980	30	40	50	55
1981	30	40	58	126
1982	26	40	55	234

Table 59. Percent occurrence (%O) and percent first randing (%1st) of food items from chain pickerel ≤400 mm in Orange Lake, Florida.

Year	1979		1980		1981		1982	
Number examined	16		95		188		69	
Number with food	8		49		102		53	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Decapoda								
Palaemonetes			26.5	20.4	34.3	22.5	39.6	15.1
Reptilia								
Natrix					1.0	1.0		
Osteichthyes								
Notemigonus crysoleucas	12.5	12.5			3.9	3.9	5.7	5.7
Fundulus crysotus			2.0		5.9	4.9		
Gambusia affinis			4.1	4.1	2.0	1.0		
Lucania goodei	25.0	12.5	26.5	24.5	3.9	2.9	11.3	5.7
Labidesthes sicculus					2.0	2.0	3.8	3.8
Enneacanthus gloriosus			10.2	10.2	8.8	6.9	5.7	5.7
Lepomis gulosus	12.5	12.5			4.9	4.9		
Lepomis macrochirus	37.5	37.5	4.1	4.1	10.8	10.8	22.6	22.6
Lepomis sp.			14.3	14.3	3.9	3.9		
Micropterus salmoides	12.5	12.5	2.0	2.0				
Pomoxis nigromaculatus					2.0	1.0		
Etheostoma fusiforme	12.5	12.5			7.8	5.9		
Notropus maculatus			2.0	2.0	2.0	2.0	1.9	1.9
Heterandria formosa			2.0	2.0				
Esox americanus					2.0	2.0		
Esox niger					2.0	2.0	1.9	1.9
Dorosoma cepedianum					1.0	1.0		
Lepomis microlophus							1.9	1.9
Unidentified			18.4	16.3	26.5	21.6	41.5	35.8

Table 60. Percent occurrence (%O) and percent first ranking (%1st) of food items from chain pickerel >400 mm in Lake Orange, Florida.

Year	1979		1980		1981		1982	
Number examined	159		80		70		17	
Number with food	66		29		31		11	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Osteichthyes								
Erimyzon sucetta	3.0	3.0			22.6	22.6	9.1	9.1
Notemigonus crysoleucas	22.7	21.2	3.6	3.6	3.2	3.2	18.2	18.2
Fundulus crysotus			7.1	7.1	3.2			
Gambusia affinis			3.6					
Lucania goodei							18.2	
Labidesthes sicculus	1.5	1.5			3.2	3.2		
Enneacanthus gloriosus			3.6	3.6	6.4	6.4		
Lepomis gulosus	1.5	1.5			6.4	6.4		
Lepomis macrochirus	15.2	12.1	28.6	21.4	22.6	22.6	45.4	45.4
Lepomis sp.			10.7	10.7	6.4	3.2		
Micropterus salmoides			14.3	14.3				
Pomoxis nigromaculatus	1.5	1.5						
Dorosoma cepedianum	51.5	50.0	3.6	3.6	3.2	3.2		
Etheostoma fusiforme	1.5						18.2	9.1
Lepomis microlophus			3.6	3.6	3.2	3.2		
Esox niger			3.6	3.6	3.2	3.2		
Unidentified	9.1	9.1	28.6	28.6	22.6	22.6	18.2	18.2

decreasing prey length occurred in the larger size group. Quantitative differences in consumption of prey by the two size groups was also evident. The small fish usually consumed only one prey item per feeding, whereas, large pickerel fed almost exclusively on one large prey item. Large pickerel shifted from consumption of gizzard shad to other species as hydrilla increased.

Young-of-year bass (75-150mm) in Orange Lake consumed freshwater shrimp, aquatic insects and small vegetation dwelling fish. Bluefin killifish were the dominant fish species consumed during all study years. This was the only bass size group for which bluefin killifish were an important dietary component. Fish in this size group fed on fish of approximately 25 mm. Insect consumption was confined to small aquatic insects such as chironomids and water boatmen. No major chronological changes occurred in the food habits of small bass suggesting hydrilla density did not cause shifts in prey consumption (Table 61).

Yearling bass (151-250 mm) food habits shifted chronologically with increasing hydrilla levels (Table 62). Consumption of shrimp increased each year, and by 1982 was the primary food item for this size group. The increase in shrimp utilization was probably caused by a reduction in fish prey accessibility created by dense hydrilla (Savino and Stein 1982). Aquatic insects were also an important part of the diet. Chironomids and water boatmen along with dragonflies and damselflies were the primary aquatic insects consumed. Fish were the other major dietary component. Unlike the other bass size groups, no specific fish species were consumed. Fish ingestion appeared related more to size (50 mm) rather than species selection. Similar to yearling bass, intermediate sized bass (251-350 mm) underwent a chronological shift in food habits (Table 63). Generally, the consumption of grass shrimp increased with increasing hydrilla. Aquatic insects were not as important as in the smaller size group. Unidentified fish remains, bluegills

Table 61. Percent occurrence (%O) and percent first ranking (%1st) of food items from 75-150 mm largemouth bass in Orange Lake, Florida.

Year	1979		1980		1981		1982	
Number examined	48		73		125		31	
Number with food	31		62		89		14	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Cladocera								
Sida	3.2	1.6						
Decapoda								
Palaemonetes	25.8	19.4	43.5	37.1	64.0	57.3	35.7	35.7
Amphipoda								
Hyllela azteca	3.2	3.2			1.1			
Hirudinea			1.6	1.6				
Diptera								
Tendipedidae (larva)	6.4	3.2						
Tendipedidae (pupae)	12.9	6.4	1.6	1.6				
Ceratopogonidae (larvae)	3.2	3.2						
Hemiptera								
Corixidae	12.9		6.4	4.8	7.9	3.4	21.4	21.4
Naucoridae					2.2	2.2		
Osteichthyes								
Fundulus chrysotus					2.2	2.2		
Gambusia affinis	3.2	3.2	3.2	3.2	9.0	4.5		
Lucania goodei	32.3	32.3	22.6	22.6	15.7	9.0	14.3	14.3
Labidesthes sicculus			1.6	1.6	1.1	1.1		
Enneacanthus gloriosus			1.6	1.6	1.1	1.1		
Lepomis sp.			1.6	1.6	1.1	1.1		
Micropterus salmoides			1.6	1.6				
Etheostoma fusiforme			3.2	3.2	1.1	1.1	7.1	7.1
Heterandria formosa			1.6		2.2			
Esox niger					1.1	1.1		
Dorosoma cepedianum					3.4	3.4		
Unidentified	29.0	29.0	19.4	19.4	12.4	11.2	21.4	21.4

Table 62. Percent occurrence (%O) and percent first ranking (%1st) of food items from 151-250 mm largemouth bass in Orange Lake, Florida.

Year	1979		1980		1981		1982	
Number examined	21		90		133		24	
Number with food	14		43		102		20	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Decapoda								
Palaemonetes	21.4	21.4	27.9	23.3	45.1	34.3	80.0	70.0
Odonata								
Libellulidae (naiad)	7.1	7.1			2.0	2.0		
Libellulidae (adult)					3.9	2.9		
Coenagrionidae (adult)					1.0	1.0		
Diptera								
Tendipedidae (larvae)	14.3							
Tendipedidae (pupae)	14.3	14.3			2.0	2.0		
Hemiptera								
Corixidae	14.3	7.1			5.0	5.0	5.0	5.0
Osteichthyes								
Ictalurus nebulosus					1.0	1.0		
Fundulus chrysotus			4.6	4.6	5.9	4.9		
Gambusia affinis			4.6	4.6	2.0	1.0		
Lucania goodei	7.1		2.3	2.3	2.0	1.0	5.0	5.0
Labidesthes sicculus	7.1	7.1	2.3	2.3	1.0	1.0		
Enneacanthus gloriosus			7.0	7.0	5.9	4.9		
Lepomis gulosus			2.3	2.3				
Lepomis macrochirus			7.0	7.0	2.0	2.0		
Lepomis sp.			4.6	4.6	4.9	3.9		
Micropterus salmoides			7.0	7.0				
Dorosoma cepedianum	7.1	7.1			6.9	4.9		
Dorosoma petenense					1.0	1.0		
Lepomis microlophus			2.3	2.3	1.1	1.1		
Etheostema fusiforme			2.3	2.3	1.0			
Notropis maculatus					2.9	2.9		
Heterandria formosa					1.0			
Unidentified	35.7	35.7	41.9	34.9	31.4	27.4	25.0	20.0

Table 63. Percent occurrence (%O) and percent first ranking (%1st) of food items from 251 - 350 mm largemouth bass in Orange Lake, Florida.

Year	1979		1980		1981		1982	
Number examined	119		63		124		16	
Number with food	73		33		85		13	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Decapoda	39.7	24.7	21.2	15.2	47.1	32.9	76.9	53.8
Palaemonetes								
Astacidae			6.1	6.1	3.5	2.4		
Ararece	1.4	1.4						
Odonata								
Unidentified (naiad)					1.2	1.2		
Libellulidae (larvae)	1.4	1.4						
Hemiptera								
Corixidae			3.0					
Gastropoda								
Heliosoma								
Osteichthyes								
Erimyzon succetta			3.0	3.0				
Notemigonus crysoleucas	4.1	4.1	3.0	3.0	1.2	1.2		
Ictalurus nebulosus	1.4		3.0	3.0				
Fundulus chrysatus					1.2			
Gambusia affinis	2.7		3.0					
Lucania goodei			6.1	3.0	2.4	1.2	7.7	7.7
Labidesthes sicculus			3.0	3.0				
Enneacanthus gloriosus	2.7		12.1	3.0	2.4	2.4		
Lepomis gulosus	1.4				1.2	1.2		
Lepomis macrochirus	19.2	19.2	3.0	3.0	7.1	7.1	23.1	23.1
Lepomis sp.	4.1	4.1	30.3	24.2	2.4	2.4	7.7	7.7
Micropterus salmoides	1.4	1.4			1.2	1.2		
Pomoxis nigromaculatus	4.1	2.7					7.7	
Dorosoma cepedianum	12.3	12.3	3.0	3.0	9.4	8.2		
Notropus macalatus	2.7	1.4						
Heterandria formosa	1.4							
Esox niger	1.4	1.4						
Etheostoma fusiforme					1.2	1.2	7.7	
Unidentifed	30.1	23.3	45.4	30.3	40.0	37.6		
Amphibia								
Rana grylia	1.4	1.4						
Salamander	1.4	1.4						

and shad were the most important fish items (Table 63). In years of increased hydrilla, small fish and grass shrimp were consumed.

Both larger size groups of bass (351-500 mm, >500 mm) consumed increasing numbers of freshwater shrimp as hydrilla increased (Tables 64 and 65). Swingle and Swingle (1967) and Colle et al. (1978) found largemouth bass did not attain adequate growth rates after a length of 250 mm unless their diet was almost exclusively fish. Utilization of shrimp by bass >250 mm in Orange Lake resulted in growth reductions due to negative energy balances. More energy was expended catching prey than was obtained by their digestion. Both size groups fed primarily on bluegills and secondarily on gizzard shad. Differences in fish consumption between the two size groups was principally size related, with bass >350 mm consuming larger fish. Examination of mean fish length consumed, revealed a larger reduction by 1982 within both size groups (Table 65). This decrease in average prey length was due to an overall reduction in average size of the principal prey species as hydrilla encroached within Orange Lake.

Largemouth bass prey on a large variety of terrestrial and aquatic organisms. The principal foods of small bass are crustaceans and insects, whereas large bass feed almost entirely on fish. Experimental food select with studies conducted with largemouth bass, however, have indicated a high degree of individual variability. Tarrant (1960) offered largemouth bass two sizes of forage under experimental conditions. He concluded that larger fish ate larger forage, but Wright (1970) found no correlation between the size of bass and the size of forage in his laboratory studies. Lewis et al. (1961) stocked largemouth bass and specific prey in small ponds. After 10 days, the ponds were drained and all remaining organisms were counted. All prey species excluding fingerlings of bluegills were consumed in significant amounts. They concluded, therefore,

Table 64. Percent occurrence (%O) and percent first ranking (%1st) of food items >350 largemouth bass in Orange Lake, Florida.

Year	1979		1980		1981		1982	
Number examined	85		122		97		18	
Number with food	40		56		48		13	
Taxon	%O	%1st	%O	%1st	%O	%1st	%O	%1st
Decapoda								
Palaemonetes	5.1	2.5	8.9	7.1	25.0	20.8	38.5	7.7
Astacidae	2.5	2.5	5.4	3.6			7.7	7.7
Odonata								
Unidentified (adult)								7.7
Unidentified (naiad)	2.5	2.5			2.1			
Aeschnidae (larvae)			1.8	1.8				
Coleoptera								
Dytiscidae (larvae)			1.8	1.8				
Osteichthyes								
Erimyzon sucetta					16.7	16.7		
Notemigonus crysoleucas	7.5	7.5			6.2	6.2		
Ictalurus nebulosus			1.8	1.8				
Gambusia affinis			1.8	1.8				
Labidesthes sicculus			3.6	3.6			7.7	7.7
Enneacanthus gloriosus			1.8	1.8	2.1	2.1		
Lepomis gulosus			5.4	5.4	6.2	4.2		
Lepomis macrochirus	7.5	5.0	17.0	17.9	8.3	8.3	30.8	30.8
Lepomis sp.	2.5	2.5	23.2	21.4	4.2	4.2	7.7	7.7
Micropterus salmoides			1.8	1.8			7.7	7.7
Pomoxis nigromaculatus	2.5	2.5	5.4	3.6				
Dorosoma cepedianum	12.5	12.5	1.8	1.8	2.1	2.1		
Esox niger	2.5	2.5					7.7	7.7
Poecilia latipenna			1.8					
Unidentified	55.0	52.5	23.2	23.2	37.5	35.4	38.5	23.1
Reptilia								
Natrix			1.8	1.8				
Amphibia								
Rana srylia	2.5	2.5						
Salamander			1.8					
Vegetation	2.5							

Table 65. Mean length of fish consumed by largemouth bass and chain pickerel in Orange Lake.

Specie Size group (mm)	Year			
	1979	1980	1981	1982
Largemouth bass				
75-150	25	25	23	27
151-250	48	43	57	
251-350	93	115	74	41
>350				
Chain pickerel				
<400	64	37	57	50
≥400	161	112	148	106

that bluegills are not vulnerable to largemouth bass as a forage species. Lewis and Helms (1964) repeated the experiment in aquaria. Golden shiners were fed on most heavily, bluegills were chosen over green sunfish, and green sunfish were chosen over bullheads and white crappies. The authors stated that difference in prey selection in the two studies were due to differences in vulnerability of organisms in aquaria versus ponds. Under experimental conditions, largemouth bass fingerlings (81-99 mm TL) preferred fathead minnows and then goldfish. Bluegills were not extensively utilized (Snow 1961). He concluded that largemouth bass show individuality with respect to food choice.

As bass grow, they shift their food habits from a diet of plankton to aquatic insects to fish. Turner and Kraatz (1920) studied the food habits of young bass (9-90 mm TL) in Ohio. Fish (9-30 mm TL) ingested entomostracans and midge larvae and an occasional fish, whereas bass 50-90 mm TL ate amphipods, larger insect larvae and an occasional fish. Kramer and Smith (1960) found that early swimming largemouth bass fry in Lake George, Minnesota, consumed copepod nauplii, rotifers and small cladocerans. After 60 mm TL, rotifers were not utilized, and by 60 mm TL, nauplii were not consumed. After 30 mm TL, a progressive increase in consumption of amphipods, adult and immature insects and fish was noted. Studies of the food habits of fingerling largemouths in hatchery ponds at Auburn, Alabama, demonstrated that fish 5-15 mm TL consumed cladocerans and copepods and at 15 mm TL ingestion of midge larvae and pupae began (Rogers 1967). From 25-40 mm TL midge larvae and pupae comprised 90% of the total volume. After 40 mm TL few copepods and cladocerans were ingested, the diet shifted to one of midge larvae, pupae and adults.

McCormick (1940), working on Reelfoot Lake, Tennessee, found bass 57-87 mm TL fed on fish, dipteran larvae, and Palaemonetes sp. Bass 185-550 mm TL fed on fish. Bass

21-50 mm TL in Buckeye Lake, Ohio, consumed crustaceans and, to some extent, insects (Ewers and Boesel 1935). Fish 50-80 mm TL fed mainly on aquatic insects, and to a lesser extent on crustaceans. Bass 81-112 mm TL fed almost entirely on fish, occasionally ingesting damselfly naiads and water boatmen.

In Clear Lake, California, largemouth bass <50 mm fork length (FL) consumed crustaceans and fish, while larger bass fed primarily on fish (Murphy 1949; McCammon et al. 1964). Largemouth bass <150 mm TL ate cladocerans and threadfin shad in Pine Flat Lake, California (Goodson 1965). Fish 150-254 mm TL foraged on fish and aquatic insects, while all larger bass fed entirely on fish.

Applegate et al. (1966) found the following progression in food habits of largemouth bass in Bull Shoals Reservoir: fish 20-49 mm TL fed exclusively on entomostracans; fish 50-99 mm TL foraged equally between fish and insects; and all larger bass fed on fish. Mullan and Applegate (1970) determined the food habits of largemouth bass in Beaver Reservoir, Arkansas. The diet followed a succession from microcrustaceans to aquatic insects, changing to fish at about 40 mm TL. Bass 50-100 mm TL fed principally on fish with aquatic insects microcrustacean being seasonally important. Fish were the principal food item of all larger bass.

Glass (1971) studied largemouth bass predation using wooden dowels to simulate vegetation. He found that as habitat complexity increased bass made fewer attempts to capture guppies (Lebistes reticularis) therefore, capture rates declined monotonically. Savino and Stein (1982) found predation success (number of captures) was reduced to near zero when artificial plant stem densities were 250 and 1,000 stems/m². They utilized laboratory pools with artificial plant stems (ropes) at varying densities to determine if bass predator-prey interactions were affected. They felt that reduced predation success by largemouth bass in habitats of increased complexity was related to the increase in visual barriers provided by plant stems as well as to adaptive changes in bluegill behavior. Hydrilla has average stem densities that approach 3000 stems/m^2 during mat conditions (Nall and Schardt 1978). Hydrilla, therefore, will cause a large reduction in predation. Crowder and Cooper (1978) hypothesized that the feeding efficiency of fish declines with increasing macrophyte density because search and/or pursuit times are increased. At high macrophyte densities, capture rates are low, thus diets are expanded to include smaller prey. Best conditions probably exist at intermediate plant densities.

Coefficient of Condition

Coefficient of condition [K(TL)=10x(weight in grams)^3/TL in millimeters)] was calculated within seasons and size groups for each individual fish species. Weight included stomach content in all species. Fish were divided into size groups based upon literature values for shifts in food habits, sexual maturity and age. Size groups were similar to those discussed previously. Colle and Shireman (1980) found coefficient of condition of Florida largemouth bass, bluegill and redear was not consistently different in Lake Wales, Florida when data was analyzed by individual growth stanzas. Sexes were pooled within seasons for data analysis.

Lake Pearl

Bluegill K(TL)s for fish >100 mm in Lake Pearl did not show chronological changes, suggesting that vegetation removal caused no improvement in growth rate (Figure 94). The two larger size groups exhibited equivalent spring-summer peaks and winter declines in condition for all study years. The small size group had a significant increase in K(TL) from Summer 1981 through Spring 1982; but, condition declined by Summer 1982 to previous levels. This condition peak coincides with the reduction in hydrilla volume that

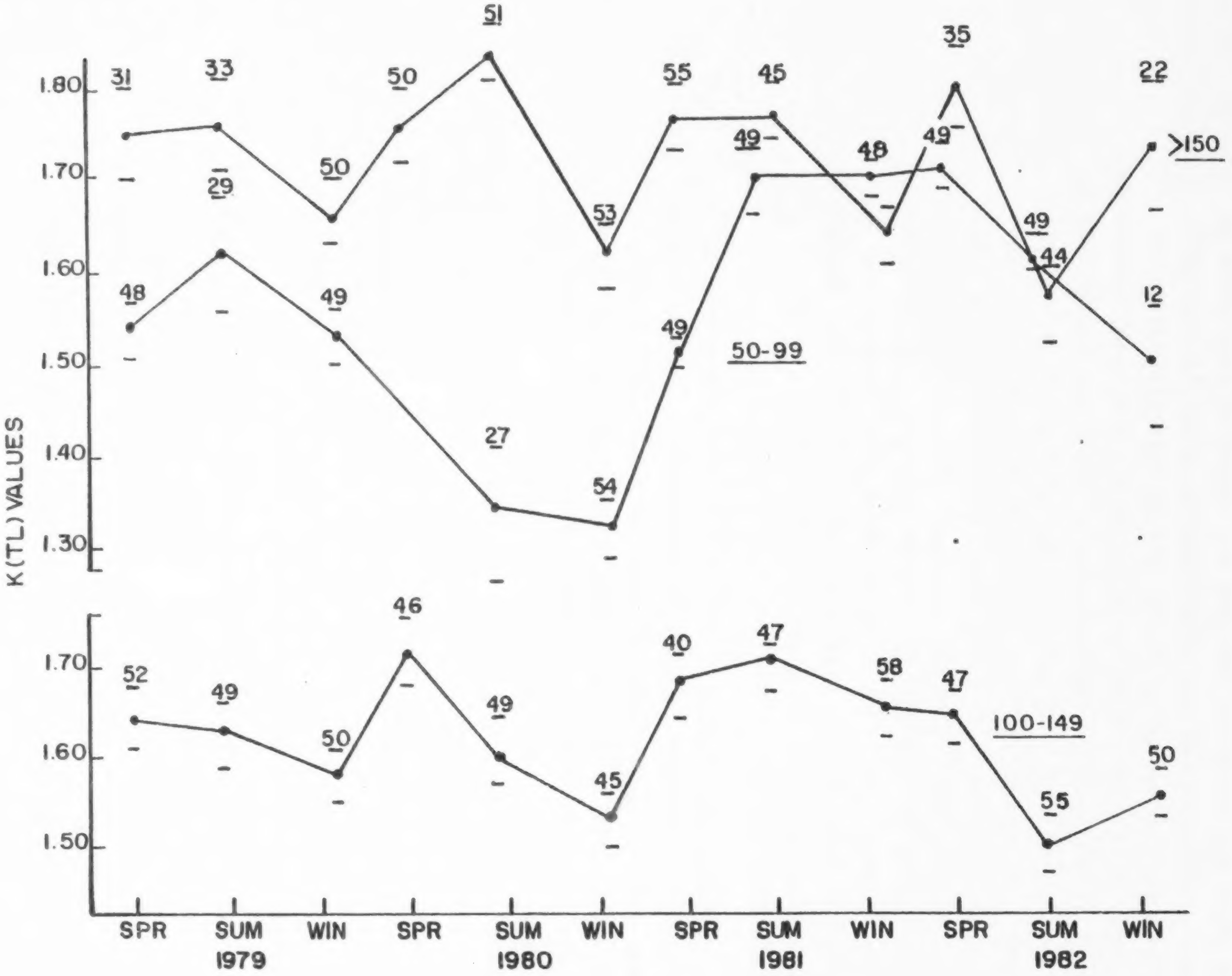


Figure 94. Mean K(TL)s for bluegill collected from Lake Pearl, Florida.

began in Summer 1981. Condition values declined after submersed vegetation was completely eliminated by 1982. Bluegill K(TL)s in Lake Pearl were approximately 1.75 for fish >150 mm, 1.70 for 100-149 mm, and 1.65 for 50-99 mm fish. Condition was not depressed as great in the two smaller size groups, but fish >150 mm had extremely low values. K(TL) for harvestable bluegill (>150 mm) should be from 2.2 to 2.4. Values below this level are indicative of slow growing fish that are just above minimum harvestable length. Carlander (1977) gave a central 50% range for bluegill K(TL) of 1.78-2.05 based on the mean of studies conducted throughout North America. Comparisons of condition values of the 100-149 mm and the >150 mm fish reveal almost identical levels, indicating little increase in length once bluegill attain a size of 150 mm. Submersed vegetation resulted in higher growth rates than no vegetation or high levels.

Crowder and Cooper (1978) also found intermediate levels of submersed vegetation resulted in higher growth rates than no vegetation or high levels. Lake Pearl bluegills >100 mm did not respond to changing vegetation levels as described by Crowder and Cooper. Shireman and Maceina (1982) reported values of approximately 1.9 for bluegill >150 mm and 1.65 for bluegill between 100-150 mm in Lake Baldwin, Florida, during Summer and Winter 1982. Lake Baldwin had been hydrilla free for two years prior to these reported values, but condition factors had been depressed prior to Summer 1982. Lake Baldwin is within 10 km of Lake Pearl; therefore, both lakes undergo almost equivalent temperature regimes.

Redear coefficient of condition in Lake Pearl revealed no significant chronological changes with decreasing hydrilla levels (Figure 95). Redear condition values indicated annual spring-summer peaks, with corresponding winter declines. Examination of the 95% confidence intervals of Lake Pearl redear K(TL)s indicate overlap

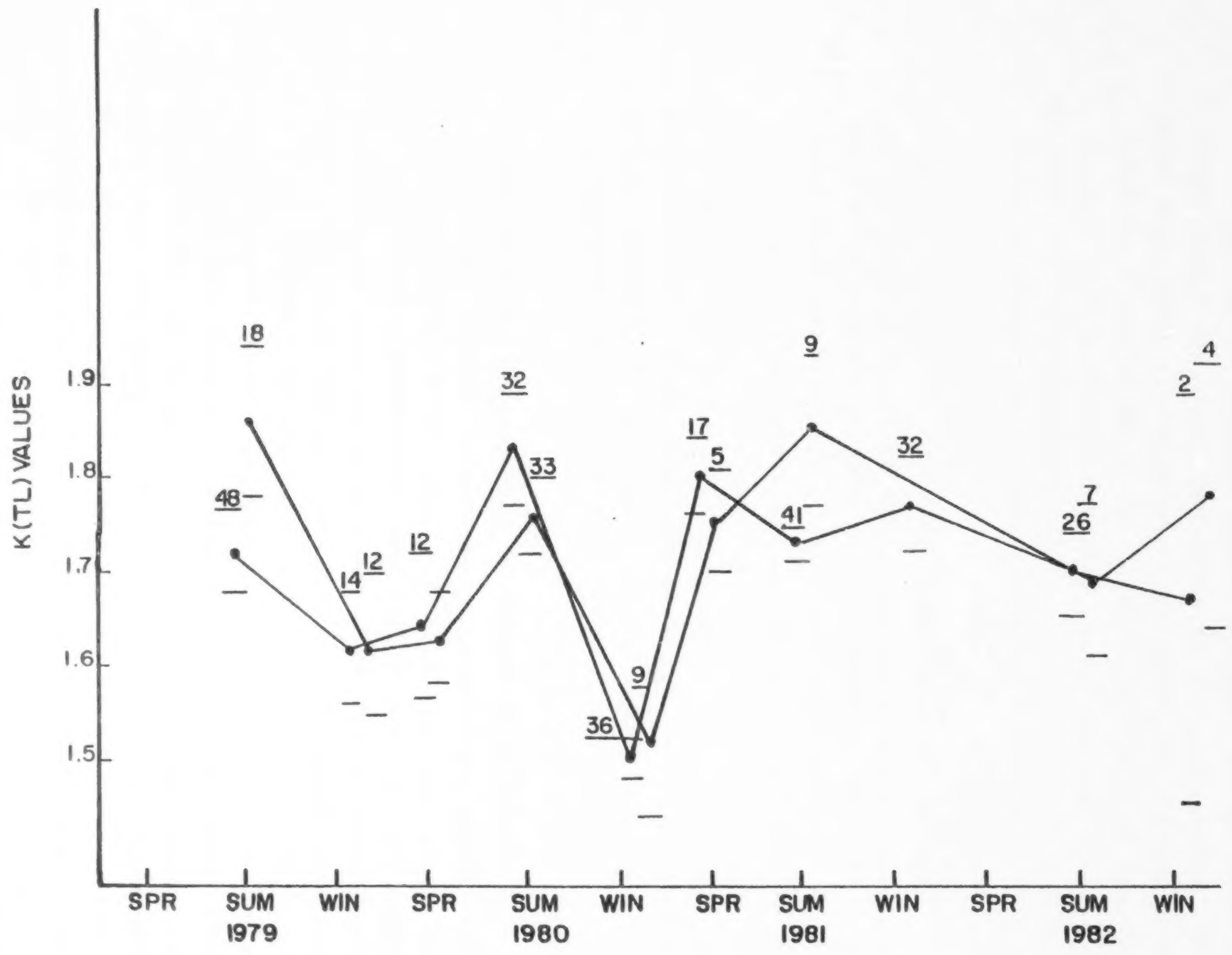


Figure 95. Mean K(TL)s for redears collected from Lake Pearl, Florida.

during all study years for both size groups, suggesting little or no growth once the fish attained 150 mm. Carlander (1977) reported ranges of 2.05 - 2.25 for harvestable redear in Oklahoma and Louisiana. Lake Pearl redear condition values were significantly lower than those reported by Carlander (1977). Although hydrilla has been controlled in Lake Pearl, redear have not demonstrated an increase in growth rate. It will probably take at least two years before redear show increased condition and growth rate.

Warmouth in Lake Pearl showed no significant changes in K(TL) that could be attributed to hydrilla density (Figure 96). Although warmouth did not undergo significant growth changes in Lake Pearl, population densities declined with the elimination of hydrilla. Warmouth sunfish are characteristically associated with aquatic vegetation and do not undergo large fluctuations in population densities as is common with other sunfishes (Larimore 1957). The reduction in warmouth standing crop in Lake Pearl is directly related to the elimination of their required habitat, submersed vegetation.

Examination of K(TL)s of Lake Pearl largemouth bass revealed no significant chronological changes occurred in any of the size groups except bass 150-249 mm; however, K(TL)s for all size groups were below normal during all study years (Figure 97). The K(TL)s for bass 150-249 mm collected during Winter 1982 were significantly lower than for those calculated for any other season. This drop in condition was attributed to inadequate sized forage within Lake Pearl. Population estimates for Winter 1982 indicated maximum population levels. The removal of all submersed vegetation by Summer 1982 allowed the large 1981 bass year class to immediately recruit into the 150-249 mm group. By the October 1982 blocknet samples, almost all bluegill (<100 mm) had been consumed, forcing bass to eat insects and shrimp, an inadequate diet, which caused a decline in K(TL).

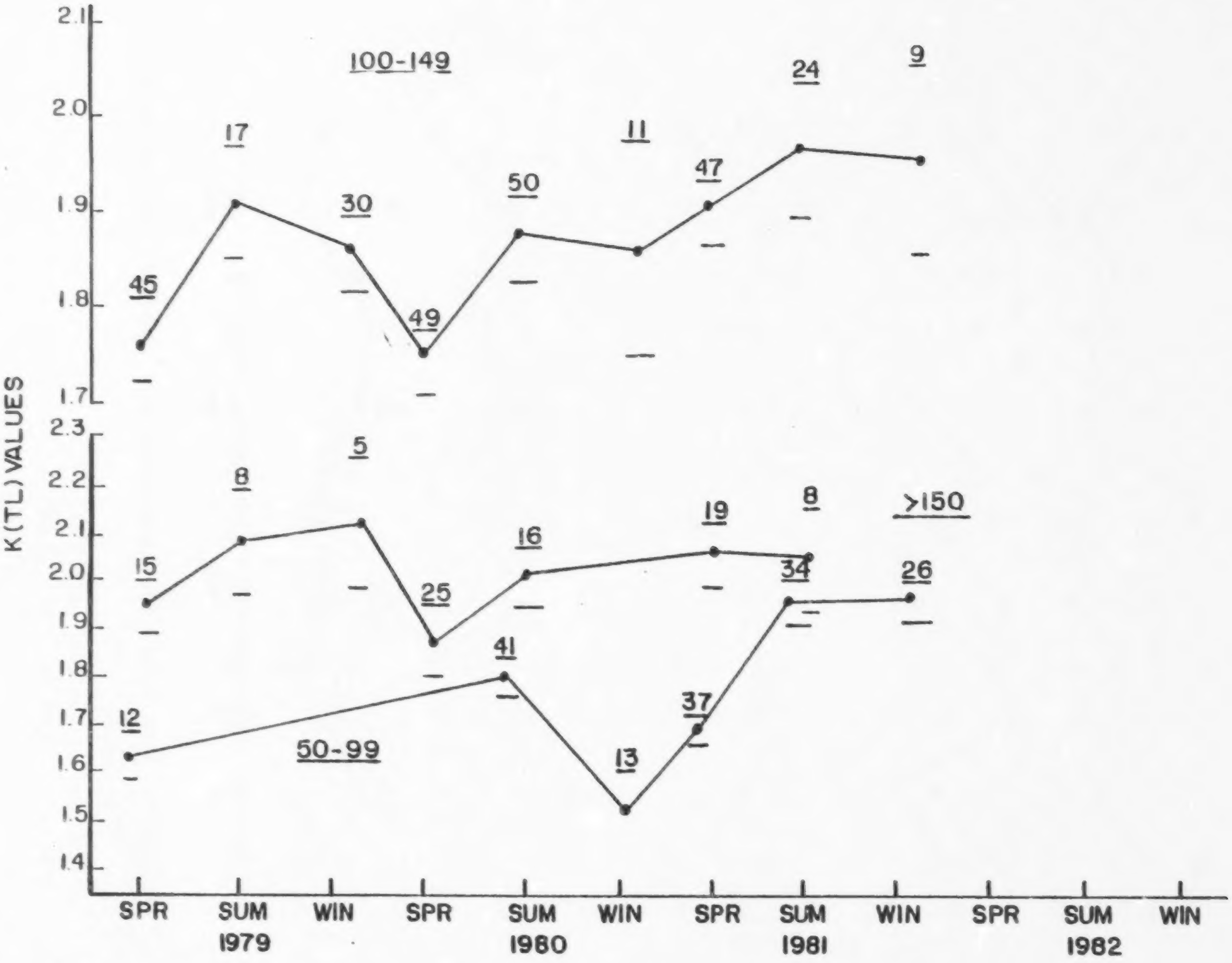


Figure 96. Mean K(TL)s for warmouth collected from Lake Pearl, Florida.

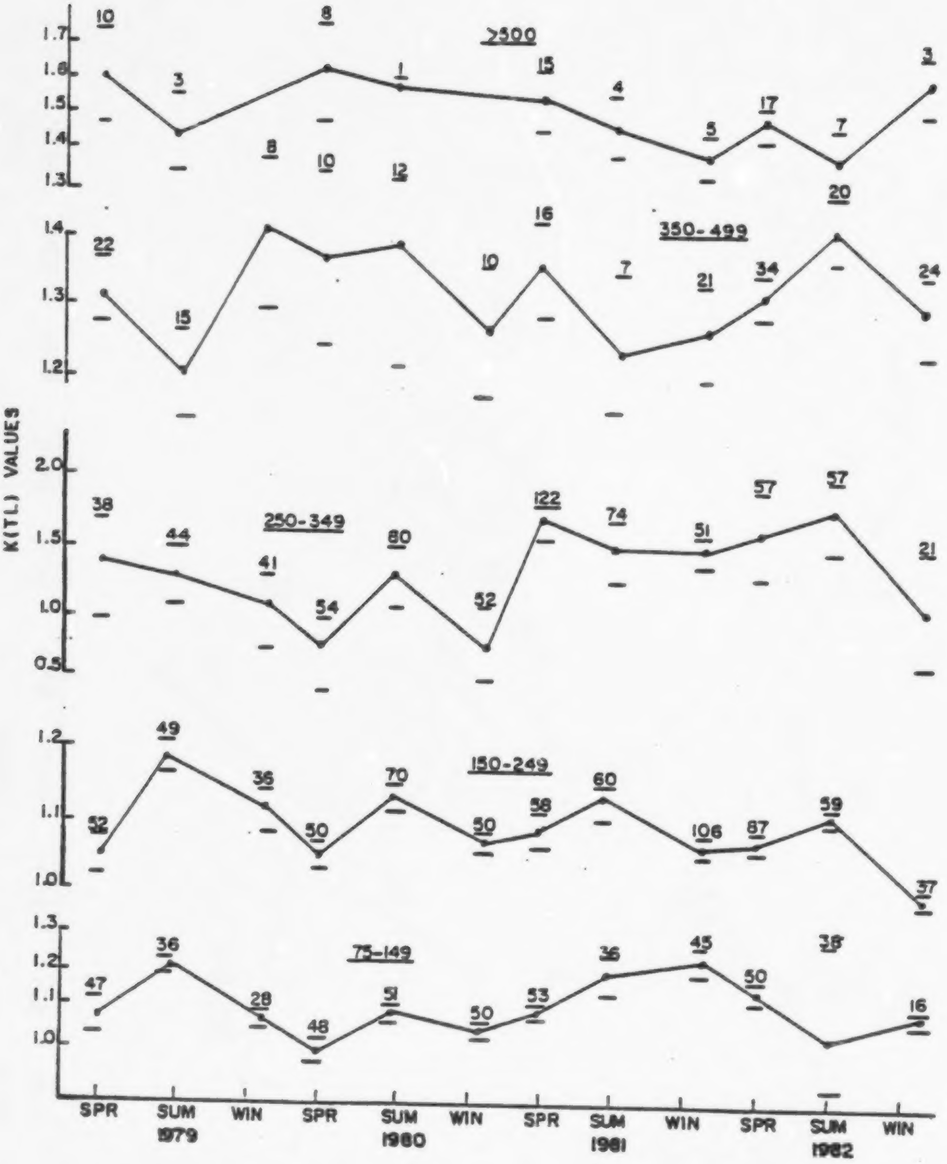


Figure 97. Mean K(TL)s for largemouth bass collected from Lake Pearl.

Carlander (1977) states that K(TL)s increase with increasing bass length, however, Lake Pearl largemouth bass did not exhibit significant K(TL) changes with increasing length until they were >350 mm. This is indicative of fish that have slower than normal growth and therefore depressed condition factors. Tagging data substantiates this reduced growth for all bass size groups. Fish <350 mm TL had extremely slow growth rates.

Orange Lake

Harvestable Orange Lake bluegill coefficient of condition declined significantly after Spring 1980 (Figure 98). Annual spring peaks decreased from 2.4 during 1979 and 1980 to 2.15 in 1981 and 1982. This reduction is indicative of a decrease in growth rate which will eventually determine the number of harvestable bluegills. The two smaller bluegill size groups (50-99 mm and 100-149 mm) revealed no significant changes in K(TL) with increasing hydrilla levels. Annual peaks in condition factors of the 50-99 mm group were equivalent for all study years in both Orange Lake and Lake Pearl, but Pearl values for bluegill >100 mm were significantly lower than comparable fish in Orange Lake.

Orange Lake redear coefficient of condition did not change significantly as hydrilla expanded to 60% coverage within the lake (Figure 99). Redear K(TL) values, however, increased annually during spring and summer and declined in the winter. Orange Lake redear K(TL)s were equivalent to values reported by Carlander (1977) for harvestable redear in Oklahoma and Louisiana.

Examination of warmouth condition factors for Orange Lake showed no significant changes that could be attributed to aquatic vegetation levels. Orange Lake warmouth, however, had higher average condition factors than Lake Pearl warmouth (Figure 100).

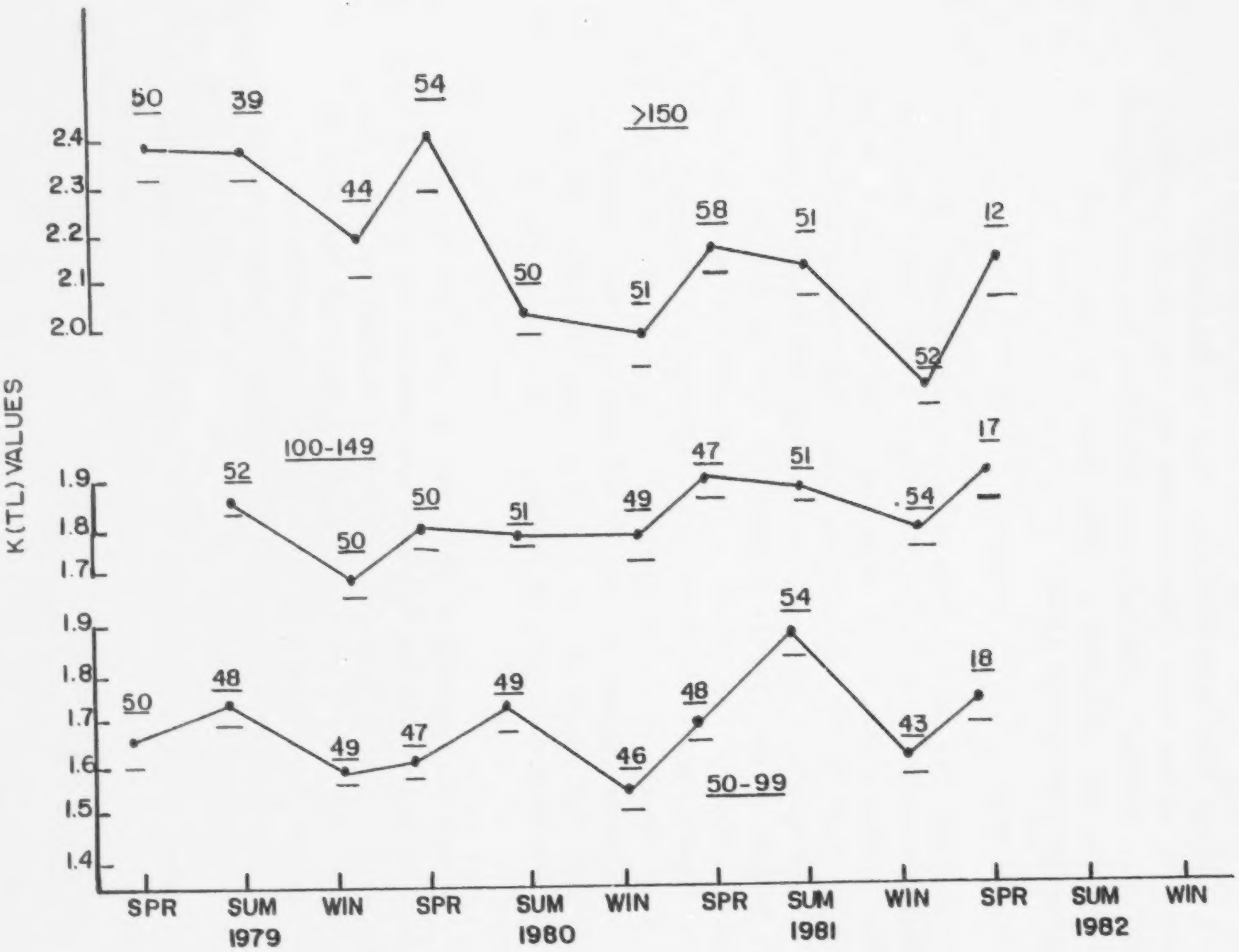


Figure 98. Mean K(TL)s for Orange Lake bluegills.

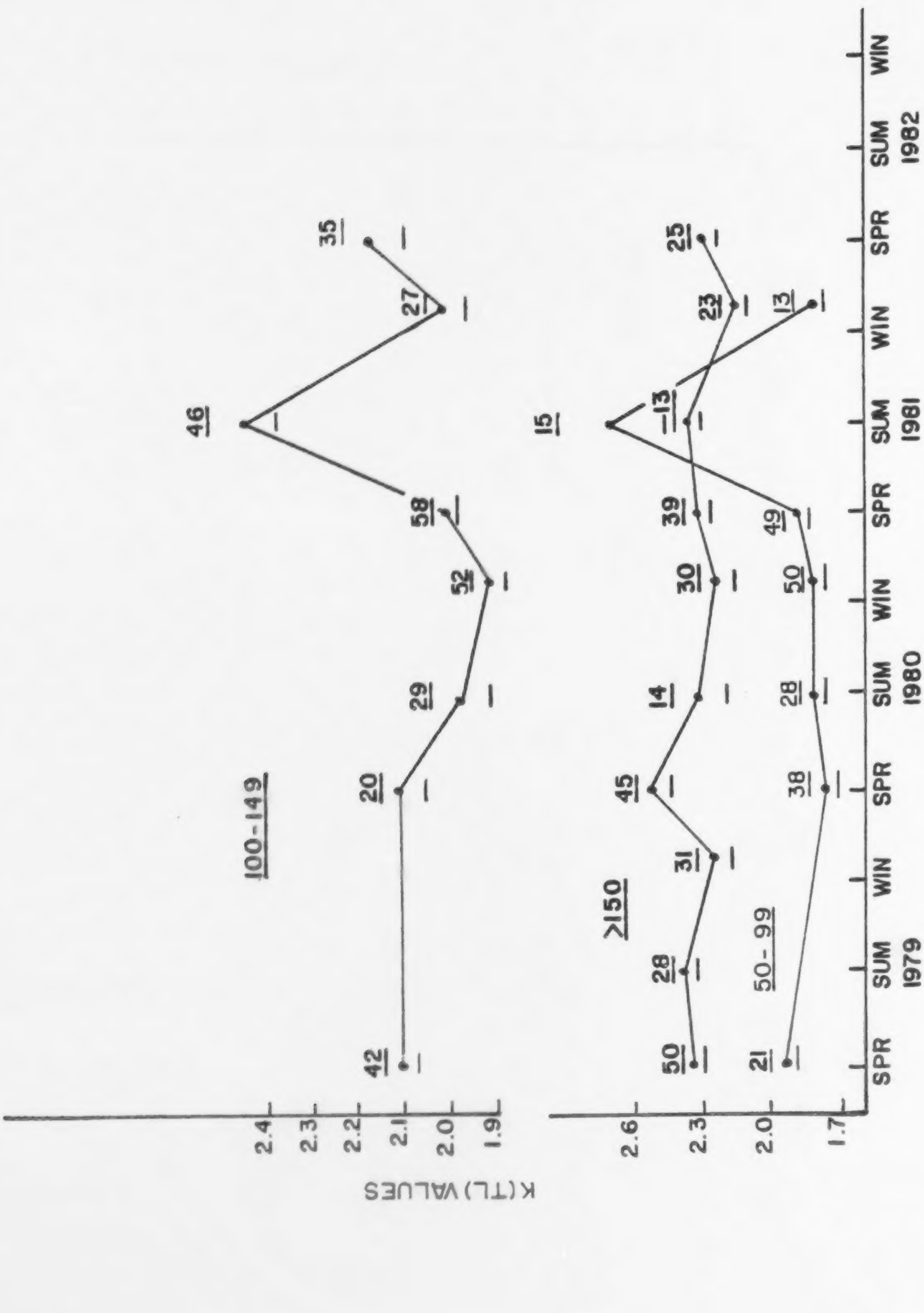


Figure 99. Mean K(TL)s for redear collected from Orange Lake, Florida.

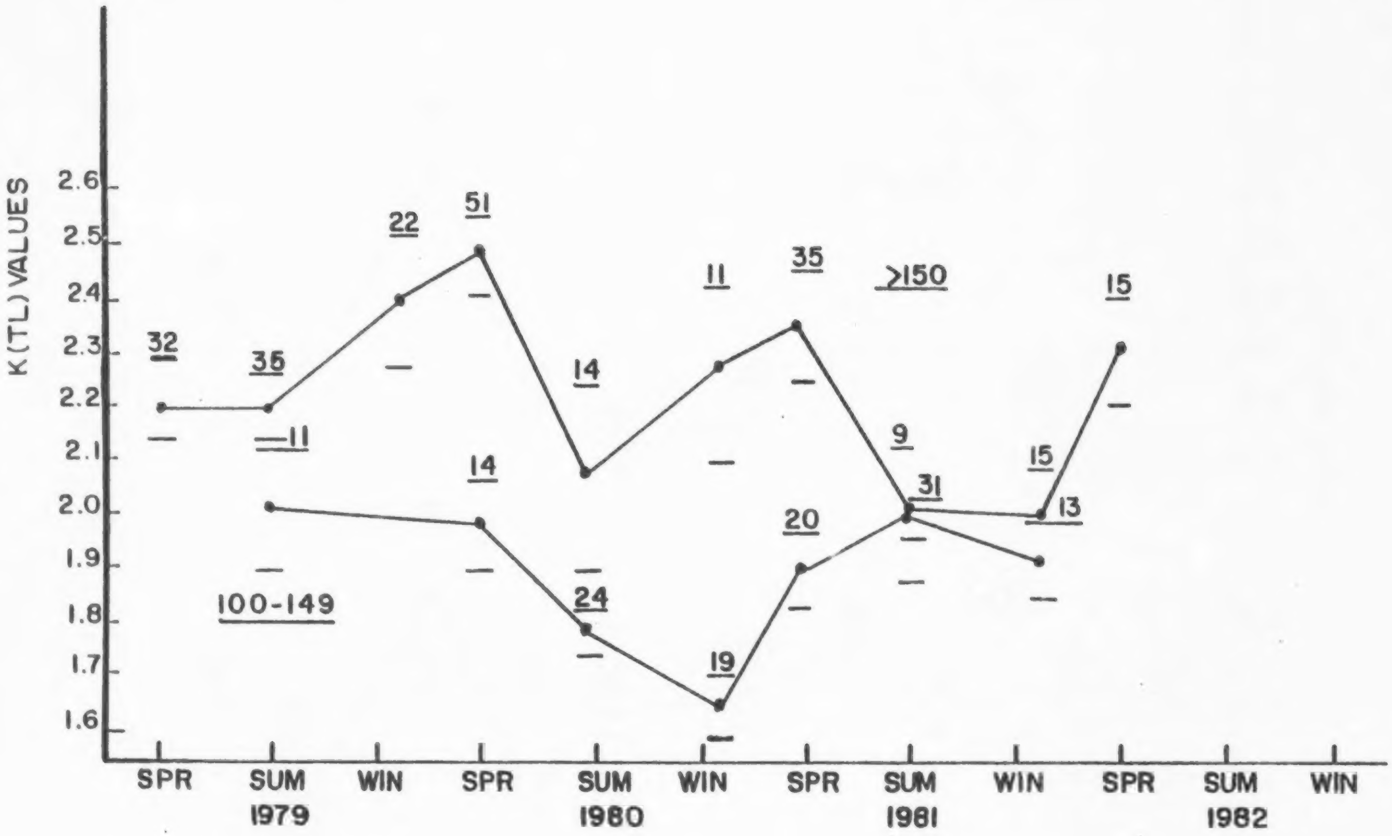


Figure 100. Mean K(TL)s for warmouth collected from Orange Lake, Florida.

The presence and changing coverage of submersed vegetation caused variable growth and condition of both bluegill and redear sunfish. Cooper et al. (1963) and Clugston (1964) both demonstrated a high correlation between condition and growth with slow growth accompanied by a continually low condition factor. Bailey (1978) reported condition factors for bluegills and redear sunfish in Arkansas generally improved with the removal of aquatic vegetation by grass carp. Bluegill and redear sunfish in Oklahoma ponds grew faster when submersed vegetation was controlled with herbicides (Cope et al. 1969; Cope et al. 1970). These authors report that vegetation removal increased food availability thereby increasing growth rates. Bluegill and redear coefficient of conditions in two Florida lakes were not adversely affected until hydrilla occupied the majority of the water column (Colle and Shireman 1980). These authors found reductions in condition values were confined to bluegill and redear >100 mm. Shireman and Maceina (1982) examined bluegill and redear condition values for three additional years in one of the lakes studied by Colle and Shireman (1980). They reported that it took two years after total hydrilla elimination for condition levels in redear and bluegill >100 mm to attain higher levels. The authors attributed the delay in K(TL) improvement for both species to population imbalances created when hydrilla was present.

Moderate hydrilla levels may produce a habitat that causes improved condition and growth for redear and bluegill >100 mm. However, if the plants are dense and occupy the entire water column a marked reduction in both growth and condition occurs. Wilbur (1969) characterized redear sunfish >100 mm as strictly benthic feeders, with smaller individuals utilizing both benthic and free-swimming organisms. He reported that distribution was related to size; larger fish were associated with open water whereas smaller redear sunfish were in submersed vegetation. Werner and Hall (1977) found bluegills to be specialized for small food items and demonstrated flexible habitat requirements. Bluegills foraged effectively on vegetation-dwelling prey in areas of abundant submersed vegetation (Potamogeton sp.) and also in open-water environments (Werner and Hall 1977).

Condition factors of Orange Lake bluegills, redears and warmouth were higher than those calculated for Lake Pearl fish. It is our opinion that Orange Lake condition factors for all size classes and species represent normal or expected values for the species at our temperature regimes. Lake Pearl condition factors are well below those reported by Carlander (1977). Shireman and Maceina (1982) report that bluegill K(TL)s fluctuated considerably in Lake Baldwin, Florida, as hydrilla levels increased and decreased, but were increasing after hydrilla was removed for two years. Reduced condition values in these systems is probably related to population numbers. In Orange Lake, for example, condition values were highest in 1979 a hydrilla-free year. Populations of juvenile bluegills, warmouth and redear sunfish numbers were high in 1977 but declined considerably in 1978. As hydrilla levels increased from 1979 through 1981, the numbers of these fish also increased. Coinciding with vegetation and fish number increases, there was a decrease in K(TL)s. Increased population numbers have long been cited as causing stunting for fish especially centrarchids (Lagler 1956; Swingle 1957).

When hydrilla coverage levels in Orange Lake exceeded 60%, bluegill K(TL)s decreased significantly. In Lake Pearl when hydrilla levels exceeded 90%, harvestable bluegill K(TL)s were significantly lower than values from Orange Lake when coverage was 60%. As hydrilla levels increased above 60%, further reductions in condition occurred. Once hydrilla invades the entire water column, bluegill above 150 mm grow slowly resulting in a population of fish of minimum size. Warmouth according to Larimore (1957) and Raney (1965) do not become dominant and stunted like many sunfish, but establish small broods without restricting the reproduction and growth of other sunfish. Our data collected within hydrilla communities indicate that warmouth undergo increases in population density, however, these increases are not great enough to depress growth.

Harvestable redear K(TL)s were significantly lower in Lake Pearl than in Orange Lake, indicating that hydrilla coverage exceeding 90% caused a reduction in redear condition factors.

Vegetation removal reverses this trend as small bluegills, redears, etc. are vulnerable to predation and the population is decreased. This releases additional food for all individuals and optimum growth occurs.

Chain pickerel condition factors in Orange Lake were usually maximal during the summer of each year and lowest during the winter (Figure 101). Significant reductions occurred over the yearly cycles. K(TL)s of pickerel >400 mm were significantly different from Spring to Winter 1980, from Winter 1980 to Summer 1981, and from Summer 1981 to Spring 1982. Although significant differences were indicated according to season, yearly values were not significantly different indicating that vegetation levels in Orange Lake did not affect the growth of pickerel >400 mm TL (Figure 101). Both size groups had maximal condition factors during 1979. Examination of prey length consumed by pickerel indicated both size groups had consumed much larger average length prey during 1979. The consumption of larger prey probably provided an increase in the energy, efficiency ratio of prey capture to metabolic use for growth resulting in maximal condition values during 1979.

Pickerel <400 mm TL exhibited greatest condition during Summer 1979 and underwent significant changes in condition through Spring 1980. Seasonal significance was not indicated in succeeding years. Herke (1959) calculated a mean K(TL) of 0.31 for 239 pickerel collected in Florida. Guillory (1979) reported a mean K(TL) of 0.52 for all

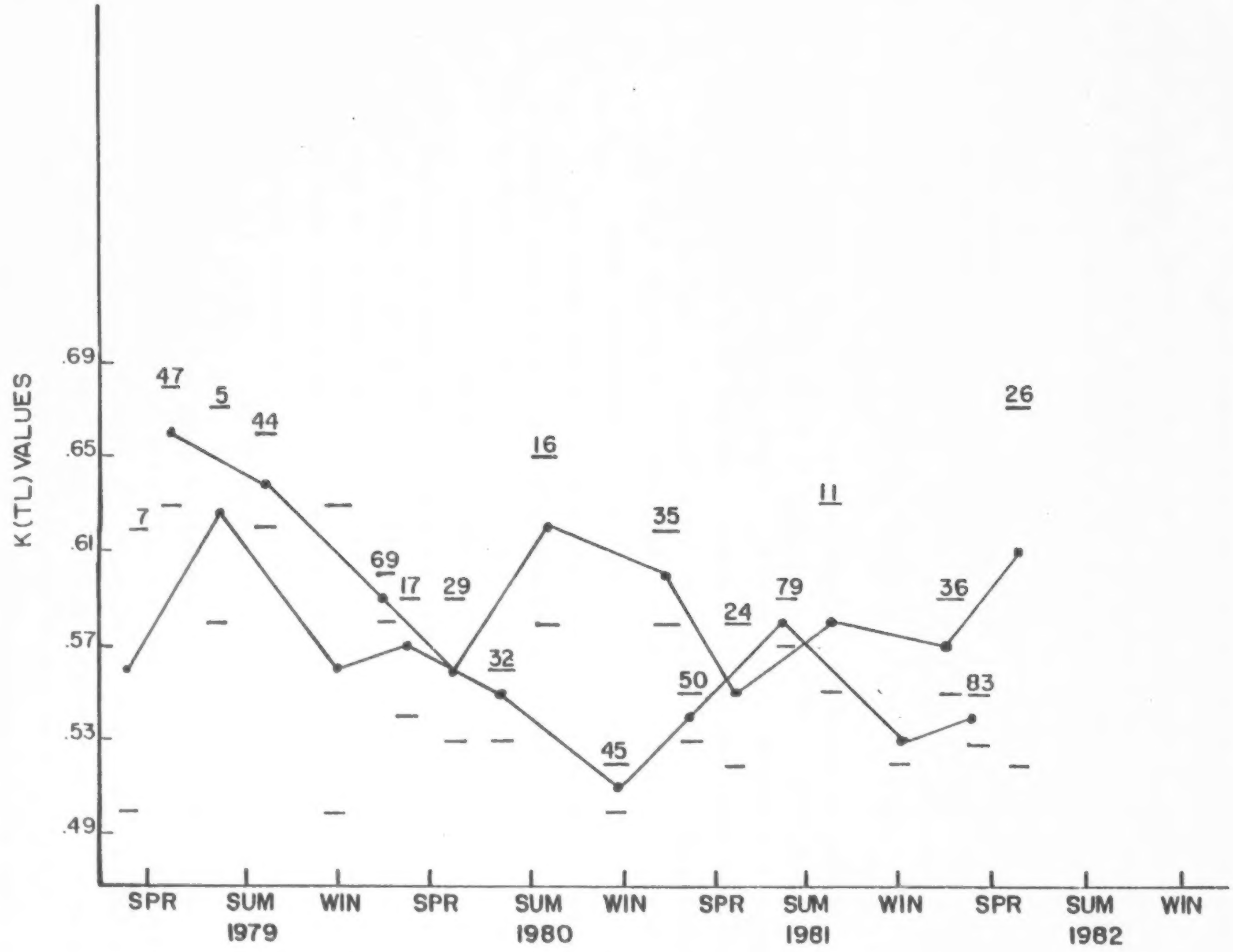


Figure 101. Mean K(TL)s for pickerel collected from Orange Lake, Florida.

pickerel size groups in Lake Conway, Florida and a maximal mean of 0.54 for 301-325 mm fish when K(TL) was analyzed by size groups. Orange Lake chain pickerel had higher K(TL)s than either of the previous studies during all seasons indicating that hydrilla levels from 18% to 65% were producing an optimal habitat for chain pickerel growth.

Chain pickerel have become a major piscivorous predator in Orange Lake. Hydrilla has not caused any significant declines in pickerel condition. Orange Lake blocknet sampling conducted by the Florida Game and Fresh Water Fish Commission in 1975 (prior to hydrilla infestation) revealed pickerel standing crop values to be <1 fish/ha. Data collected during this study has shown an increase in pickerel density to 110 individuals/ha. Although no significant improvement in pickerel condition was evident with increasing hydrilla levels, the creation of an additional vegetated habitat has caused tremendous increases in their standing crop.

Harvestable Orange Lake bass underwent significant reductions in condition factors with increasing hydrilla levels (Figure 102). Hydrilla percent coverage increased from 17% to 65% from 1979 to Summer 1980. All size groups of bass >250 mm underwent significant declines in coefficient of condition and in turn growth as hydrilla expanded into the littoral native vegetation communities. Colle and Shireman (1980) found hydrilla levels in excess of 30% caused immediate reductions in harvestable bass. Both smaller size groups of bass underwent a significant peak in condition during Summer 1981; however, values after this time period decreased to levels found during previous study years. Hydrilla coverage reached approximately 77% in 1982, but neither size group <250 mm revealed any decline in coefficient of condition. Bass <250 mm in Lake Wales, Florida underwent reductions in condition when hydrilla coverage increased above 50%. Lake Pearl bass <250 mm had significantly lower K(TL)s than Orange Lake bass when

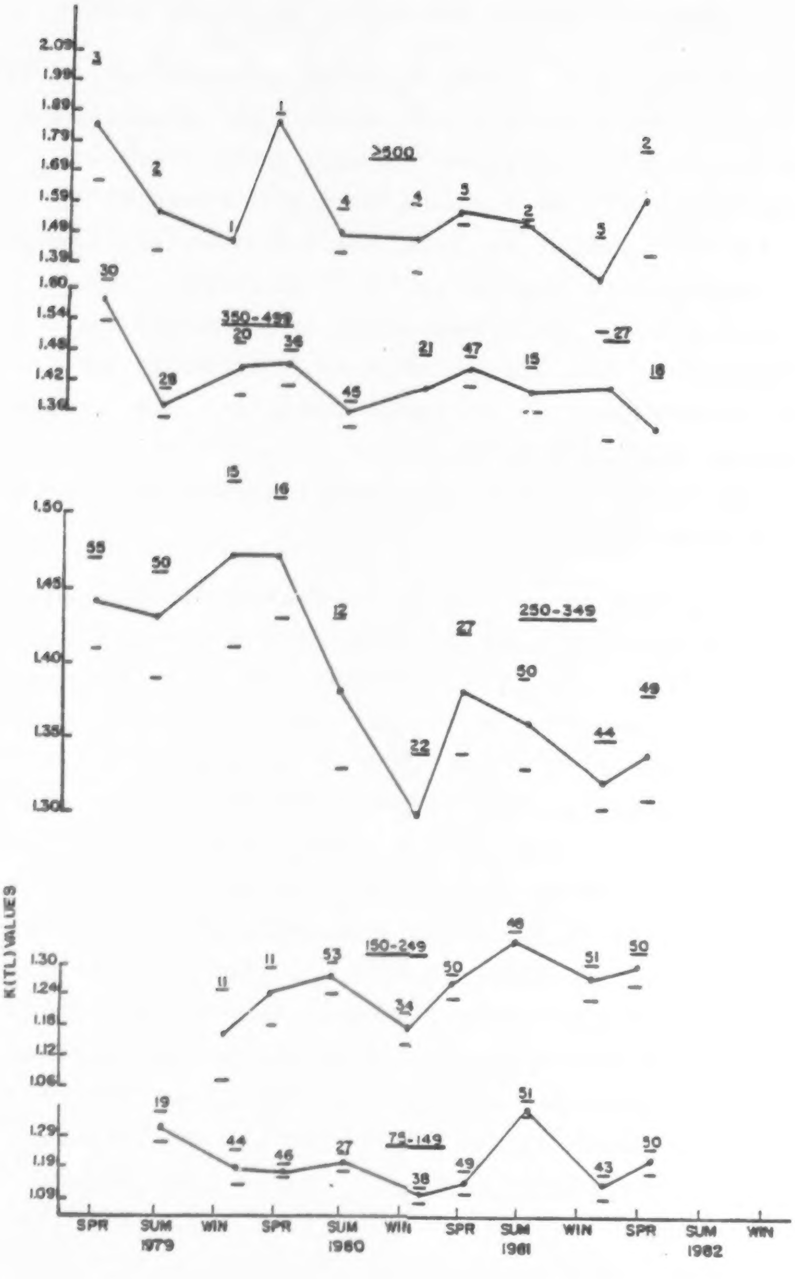


Figure 102. Mean K(TL)s for Orange Lake largemouth bass.

hydrilla coverage was >90%. Annual peak K(TL) values prior to hydrilla decline in Orange Lake were: 1.84 for fish >500 mm, 1.59 for 350-500 mm, 1.47 for bass >250-349 mm. Lake Pearl peak values were: 1.60 for >500 mm bass, 1.40 for 350-500 mm, and 1.15 for fish 250-349 mm. Juvenile fish in Orange Lake had the following K(TL) values 75-149 mm were 1.30 and 150-249 were 1.34; while Lake Pearl bass had 1.20 for fish 75-149 mm and 1.18 for bass 150-249 mm.

The removal of aquatic macrophytes has resulted in improved condition for largemouth bass, according to other studies. Bailey (1978) found plant removal by grass carp in Arkansas lakes resulted in improvement in largemouth bass condition factors. Lakes with 10-40% vegetative cover before macrophyte elimination exhibited more improvement than either totally vegetated systems or lakes with little or no initial vegetation. An extensive die-off of submersed aquatic plants in Illinois was followed by increased condition caused by extensive feeding on the released forage (Bennet 1948). Colle and Shireman (1980) reported harvestable (>250 mm) largemouth bass had low condition values once hydrilla coverage was above 30%, but smaller largemouth bass were not adversely affected until percent coverage exceeded 50%.

Largemouth bass in both study lakes underwent reductions in coefficient of condition due to the presence of hydrilla. Bass growth reductions due to hydrilla are accentuated within the larger size groups due to a difference in food intake requirements. The juvenile fish (<250 mm) can attain adequate growth on a diet of aquatic insects, shrimp and small forage fishes. The harvestable fish are not able to achieve optimal growth on consumption of insects, shrimp and small forage fish. The growth and high survival of juvenile fish causes increased numbers of fish of harvestable length (250 mm). These fish, however, do not recruit into the next size class because the required piscivorous forage base confined within the hydrilla is unavailable. Aggus and Elliott (1975) found that young bass must consistently utilize forage fish and forage fish availability is the primary factor in determining year class strength. This substantiates the importance of abundant forage fish early in the growing season. Decreased predation coupled with large prey base for small bass results in extremely high survival rates of yearling bass. Due to limited natural mortality, after the first year of growth, extremely large populations of slow growing bass result.

Laboratory studies have shown that largemouth bass and other piscivorous fishes prey capture success is significantly reduced with increasing habitat complexity (Glass 1971; Ware 1972; Savino and Stein 1982). Both Orange Lake and Lake Pearl harvestable bass reflected a large decrease in growth as hydrilla increased. This reduction in growth correlates with the laboratory studies which found prey capture success approached zero as habitat density increased. Hydrilla stem density in natural systems is much greater than any of the levels used under experimental conditions. Food habits from both systems revealed reduced sizes of prey consumed, resulting in a decrease of benefit cost rates of foraging. Fish size may have much to do with prey capture rates at a particular level of structure (Cooper and Crowder 1978). Hydrilla, due to its restriction of predators, forces harvestable sized bass to utilize much smaller forage fish. The large fish lose their ability to select larger forage fish due to the physical constraint on predation and therefore utilize the most readily available or abundant prey source.

Telemetry

Lake Pearl

The science of underwater biotelemetry is relatively new. The first published work on underwater instrumentation was by Trefethen (1956), and Johnson (1960) published information on field application. Most of the early works were with ultrasonic systems and radiotelemetry was not used until the mid 1960s (Mackay 1964).

Due to the rapid attenuation of radio signals in water, underwater reception is greatly limited by distance. The refractive qualities of the air-water interface allow only the rays reaching the surface at an angle within 6 degrees of vertical to break into the atmosphere (Stasko and Pincock 1977). Radiotelemetry presently has great potential in fresh water up to depths of 50 m (Anon. 1975; Winter et al. 1973). The reception of radiotelemetry systems is relatively unafffected by turbulence, weeds, thermoclines, or algae. These conditions often render ultrasonic systems virtually useless (Schiefer and Power 1972; Ziebell 1973).

Ten radio tagged grass carp and nine radio tagged largemouth bass were released into Lake Pearl and monitored to determine their behavior (Table 66). Both grass carp and bass preferred water depths that averaged just over 2 m. Bass traveled approximately half the distance per day as grass carp, but grass carp remained significantly farther from shore (Table 67).

A grid system was used to aid in data interpretation (Figure 103). Grass carp exhibited a definite preference for the area at the mouth of the creek (grid 7) which connects Lake Pearl and Lake Burkett (Table 68).

Table 66. List of radiotag implants in grass carp and largemouth bass in Lake Pearl.

Species	Length (mm)	Weight (kg)	Transmitter Number	Date Stocked
Grass carp	822	6.55	15451	2/20/80
"	822	7.57	15447	2/20/80
"	837	7.10	15556	2/20/80
"	625*	5.25	15463	4/8/80
"	625*	5.25	15474	4/8/80
"	625*	5.25	15470	4/8/80
"	847	8.00	15445	4/8/80
"	622	5.55	15472	4/8/80
"	625*	5.25	15454	4/8/80
"	600	3.40	15480	4/8/80
Largemouth bass	584	2.71	15462	2/7/80
"	469	1.43	15473	2/6/80
"	593	3.82	15459	2/19/80
"	592	3.31	15965	2/20/80
"	587	3.25	15475	2/20/80
"	608	4.34	15449	2/20/80
"	491	2.00	15478	2/20/80
"	633	4.29	15450	2/20/80
"	589	3.09	15457	2/20/80

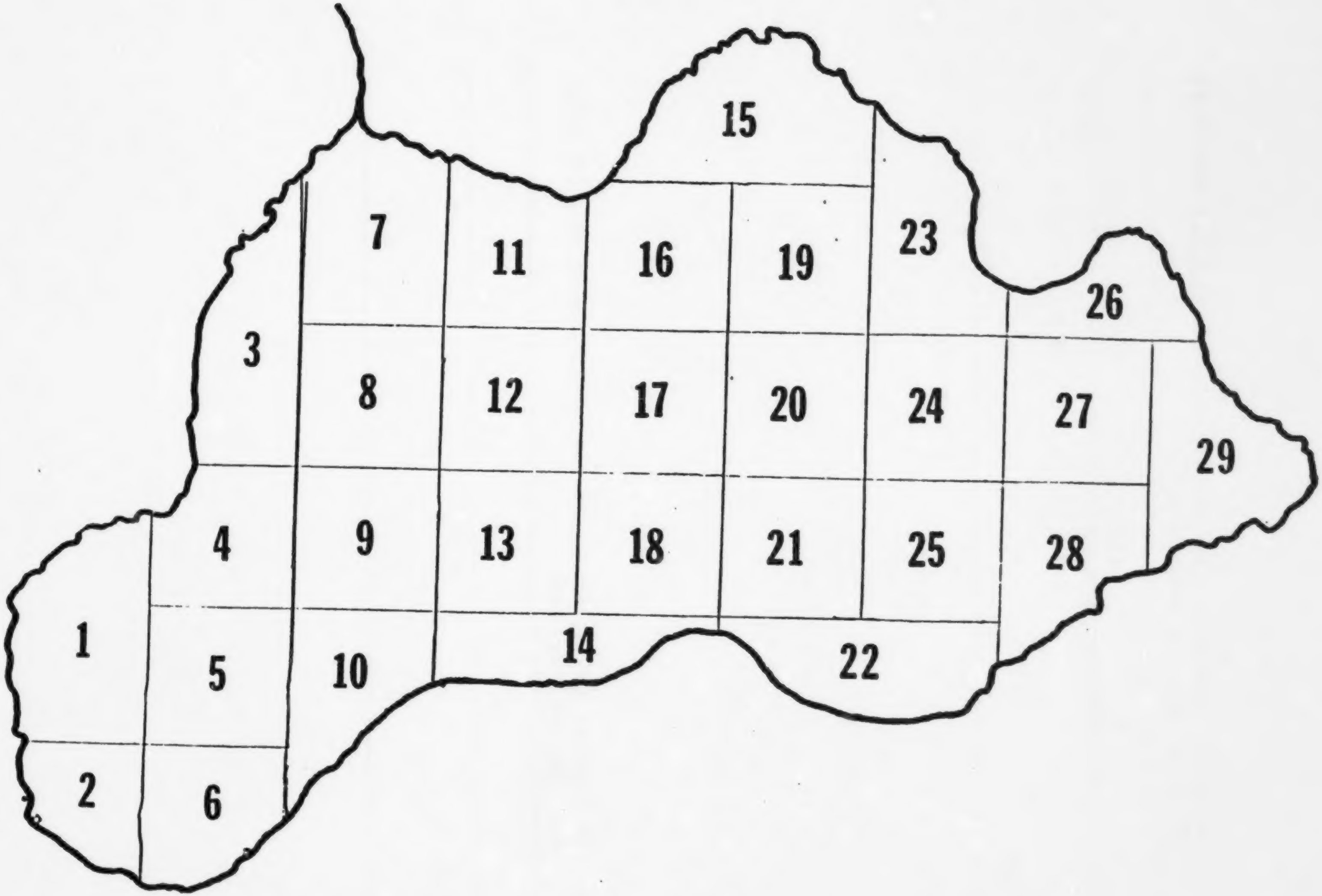
*Approximate lengths

Table 67. Depth (D), meters traveled per day (M/d) and distance from shore (D/S) for bass and grass carp.

	D(m)	M/d	D/S(m)
Bass	2.2	28.7	50.6
Grass Carp	2.4	20.0	73.0

Table 68. Grid number and percent occurrence of sighting at selected grids for bass and grass carp.

	No.	%	No.	%	No.	%
Grass Carp	7	19	8	15	3	7
Bass	4	7	1	7	5	6


15
7
11
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19
23
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12
17
20
24
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4
9
13
18
21
25
28
1
5
10
14
22
2
6

Figure 103. Grid map of Lake Pearl used for data analysis of fish radio telemetry sightings.

Approximately one-fifth of the total grass carp sightings occurred in grid number 7 and locations in grids 3, 7 and 8 comprised 41% of the total locations. When grids 11 and 12 were added, the 4 ha area in this cove accounted for over half the total grass carp locations. The affinity for this area was not changed by herbicide treatment as grass carp locations pre and post herbicide application remained consistent (Table 69).

Table 69. Frequency and percent occurrence of observations of grass carp and bass during pre and post herbicide treatments.

		Pre		Post	
		%	Freq.	%	Freq.
Grass Carp	Herbicide	82	91	79	168
	Non Herbicide	18	20	21	45
Bass	Herbicide	54	73	60	112
	Non Herbicide	46	62	40	75

Seven of the eight tagged grass carp were usually located in discrete areas which varied from 0.4 to 1.6 ha. Radiotelemetry, electrofishing samples and incidental sightings indicated that grass carp were strongly gregarious. Species specific behavior for grass carp was evident. Although individual grass carp preferred specific areas of the lakes they often moved extensively. Visual observations also indicate that the untagged smaller grass carp, stocked for weed control exhibited similar behavior. Grass carp did not show a preference for either the treated or non treated end of the lake.

Two of the six bass used for analysis established and maintained home ranges. Established ranges were considerably larger than those reported by Warden and Lozio (1975). Increased home range size or lack of home range might be due to the degree of vegetation cover. The extensive hydrilla coverage greatly reduces intra-specific contact and thus reduces the necessity of defendable territories.

Bass did not exhibit preferences for either the treated end or control portion of the lake, but hydrilla control was not complete in the treated portion before the tags lost battery power.

Bass Spawning

Lake Pearl

Largemouth bass spawn in the spring when the water temperature is between 15 and 24 C (Kramer and Smith 1962; Swingle 1956). Other factors, such as photoperiod (Caldwell et al. 1957) and physical condition of the fish, and water transparency (Swingle and Smith 1950) also appear instrumental in initiating spawning. The Florida spawning period stretches from January through June with major activity from March through June (McLane 1955). Bass build nests similar to those of bluegill, but never in tight groups (Swingle and Smith 1950; Carr 1942). Nests have been recorded in depths of 0.15 to 1.3 m (Heidinger 1975; Swingle and Smith 1950) usually on hard bottoms. Most spawning occurs near dusk or dawn (Carr 1942; Kelly 1962; Reighard 1906). Sexual maturity seems related more to size than age. Females reach sexual maturity at about 25 cm and males mature at a slightly smaller size (James 1939) but neither mature at an age younger than 10-12 months (Swingle and Smith 1950).

Bass bedding activity was observed and recorded in Lake Pearl on March 4 and April 8 (Figure 104 and 105). Definite preferences for spawning sites were observed. Miller and Kramer (1971) noted the grouping of bass beds along certain shorelines and theorized that selection was based on warmer water and wind protection. Besides the clumping of beds along a shoreline, an apparent preference for the treated portion of the lake was noted during the March 1981 sample (Table 70). We hypothesize that bass were choosing the treated portion of the lake because hydrilla was not matted, but growing straight up from the bottom. In the non treated end, hydrilla plants were long and stringy and were lying

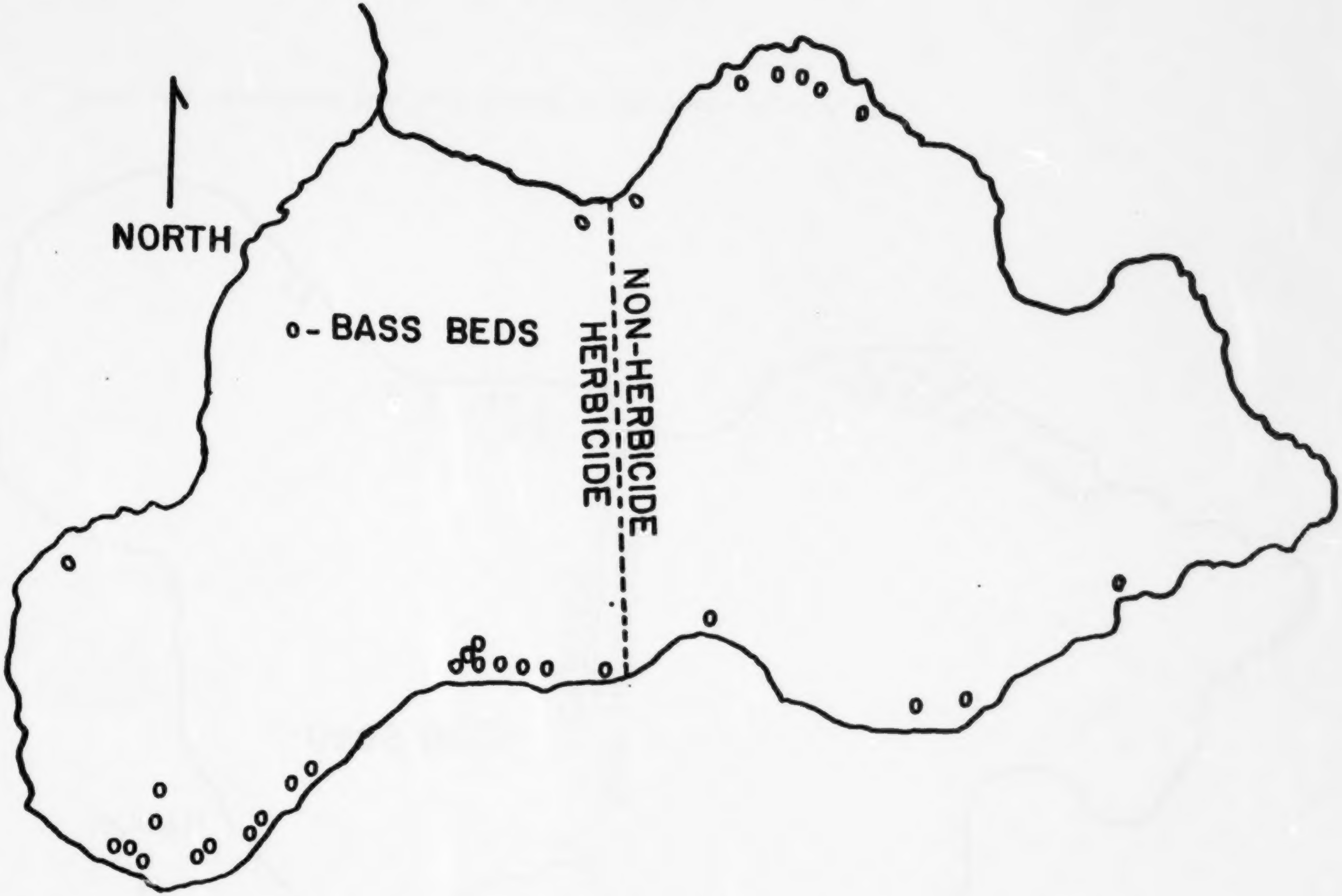
NORTH
o- BASS BEDS
NON-HERBICIDE
HERBICIDE

Figure 104. Largemouth bass beds located on Lake Pearl, March 4, 1981.

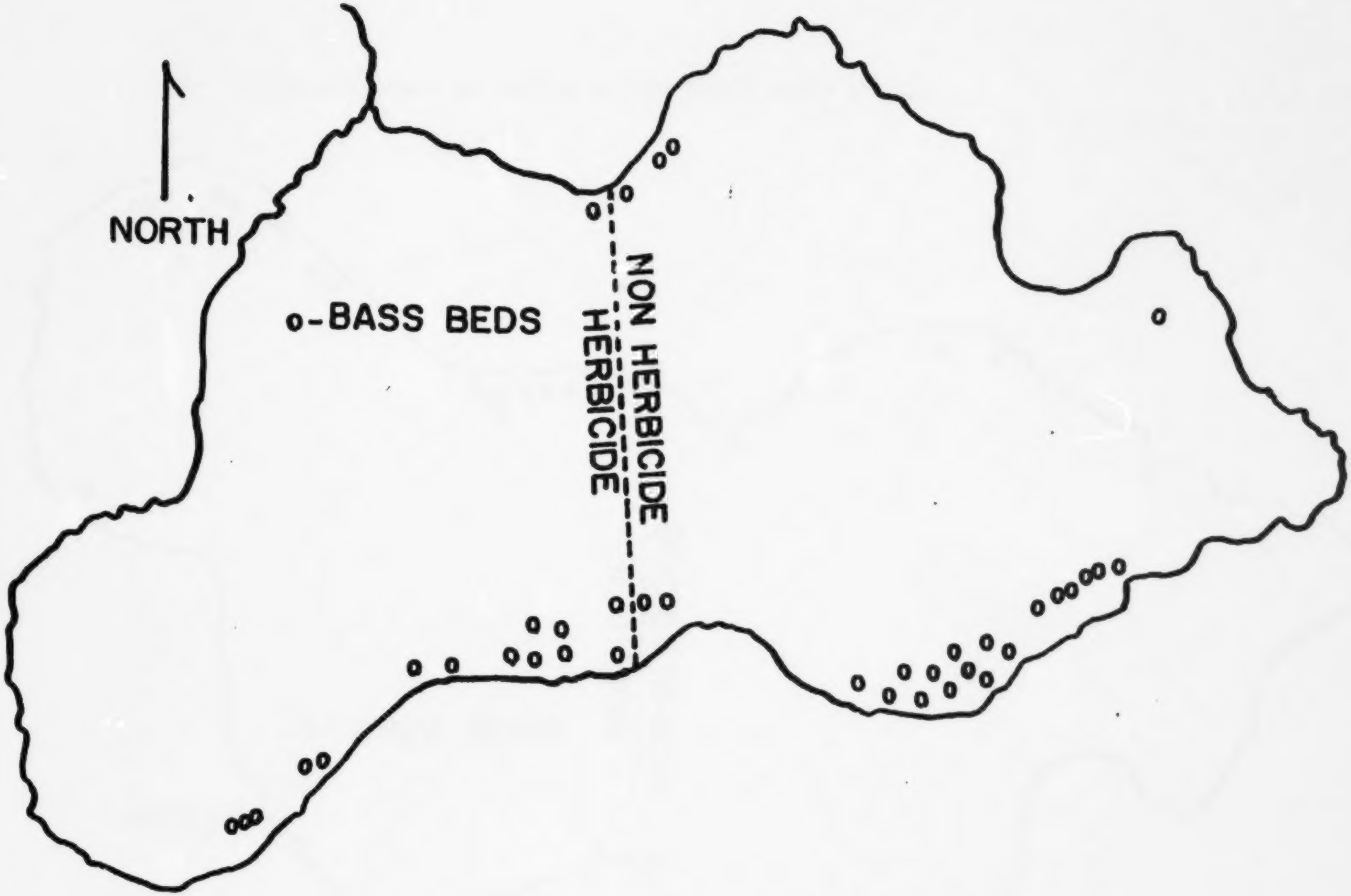
NORTH
o-BASS BEDS
NON HERBICIDE
HERBICIDE

Figure 105. Largemouth bass beds located on Lake Pearl, April 8, 1931.

Table 70. Largemouth bass spawning activity in Lake Pearl.

Date	$\bar{x}$ depth	$\bar{x}$ distance from shore	% in Herbicide area	% outside Herbicide area	% in Hydrilla	% in Nymphae	% in Panicum	% in Nuphar	% in Sand
3/4/81	0.7 m	31.0	71	29	100	39	3	3	100
4/8/81	0.9	33.8	40	60	100	12.5	2.5	20	97.5

flat on the bottom which made it difficult for bass to build nests. This trend was reversed during the April sample (Table 70). Hydrilla in the treated portion during April was dense in the shallow water areas, whereas in the non treated area it had not recovered from winter senescence and was much less dense; therefore, the bass preferred the non treated areas during April. During the winter cold period, hydrilla in the treated portion was green and remained close to the bottom where it received protection from cold temperature. The hydrilla in the non treated end was surface matted and experienced a severe winter "die-back". This phenomenon was observed in many Orange County lakes (Nick Sassic, O.C.P.C., personal communication).

The correlation between bass bedding and hydrilla is one of propinquity. However, there seems to be a preference for spawning areas that include both hydrilla and floating leafed plants rather than either 100% hydrilla or hydrilla and maidencane. Visual observation of spawning sites could not be continued because as plants were controlled, water turbidity increased which made visual nest sightings impossible.

Bass Growth and Population Estimates

Lake Pearl

A total of 1311 bass were tagged (Table 71) and tag retention rates were 89% for bass 151-250 mm; 64% for fish 251-350; and 56% for bass >350 mm. Longest tag retention to date has been 1111 days. Wilbur and Dochrow (1972) calculated retention rates of 88% for bass tagged with similar floy tags. They reported all losses were due to tag dislodgement from the fish. Our findings were similar prior to the October 1980 collections. Tag loss, however, increased tremendously during the November and December 1980 collections and the February 1981 sample. Eighty percent of the tag loss during this time period was attributed to fish tagged during the August and October 1980 collections. Defective tags were used during these two sample periods as the fish did not lose tags, but the numbered plastic sleeve separated from the anchor. New tags were purchased and used in all subsequent sampling. Tag separation, continued to be a problem in bass >250 mm. Periphyton and filamentous algae caused the separation of the numbered plastic sleeve from the monofilament insertion. After 1982, floy tags treated with algacide were used, but separation losses continued with no change.

Growth data from recaptured floy tagged bass were divided by year and size group for data analysis (Table 72). Recapture information was used from bass tagged and recaptured within a single year. Length frequency histograms revealed bass in the 150-250 mm size group were two years old. Hydrilla attained maximum coverage in Lake Pearl during 1977, causing large increases in population densities of young-of-year (YOY) bass which recruited into the 151-250 mm size groups. Growth rates in 1980 for the 151-250 mm fish were significantly greater than 1982 with respect to mm/day growth, gm/day growth, mean length and mean weight. Growth in 1981 was greater than 1982 but not as rapid as the first study year. Although growth was

Table 71. Number of largemouth bass floy tagged and recaptured in Lake Pearl.

	Number tagged			Number recaptured with tag			Recaptured-no tag		
				Size Group					
	151-250	251-350	>350	151-250	251-350	>350	151-250	251-350	>350
2/14/79		32	32						
6/20/79		37	14		2	3			
10/16/79		15	3		1				1
2/5/80	10	48	7		5	1			2
2/19/80					1	1			
5/12/80	15	37	14	1	10	3			
5/28/80	16	55	12	1	1	1		1	
8/26/80	48	40	5		6	3		2	
10/28/80	31	38	8	2	9	1		4	
12/8/80	27	53	11	5	6	2	2	8	2
2/16/81	42	101	25	8	20	6	1	16	4
6/4/81	33	51	7	3	22	4		2	
10/28/81	87	43	17	3	7	2	1	4	5
2/16/82	59	30	26	4	10	6	1	10	11
6/2/82	45	41	30	1		2		8	5
11/7/82	36	17	13	2	2	9		3	5
Totals	449	638	224	39	102	44	5	58	35

Table 72. Growth rates of floy tagged bass in Lake Pearl

Length	Year	Mean Total Length (mm)/95% Confidence Interval	Mean mm/day Confidence Interval	Mean Weight/95% Confidence Interval	Mean gm/day 95% Confidence Interval
151-250	1980(13)	245 234 - 256	.23 .15 - .31	154.7 130.1 - 179.1	.28 .20 - .36
	1981(13)	242 221 - 263	.10 .06 - .14	155.9 101.7 - 210.1	.19 .05 - .34
	1982(28)	219 213 - 225	.07 .05 - .09	110.5 100.1 - 120.9	.08 .07 - .09
251-350	1980(27)	299 289 - 309	.08 .05 - .11	299.0 266.7 - 331.2	.12 -.02 - .26
	1981(25)	303 295 - 311	.06 .03 - .08	308.8 277.7 - 340.0	.10 -.05 - .25
	1982(25)	315 302 - 328	.09 .06 - .12	383.7 326.1 - 441.2	.32 .11 - .53
351-500	1980(3)	412 368 - 456	.05 -.02 - .12	876.7 545.1 - 1298.3	-.30 -1.38 - .78
	1981(3)	429 385 - 473	.06 0 - .12	1065.4 615.8 - 1515.0	.58 -.58 - 1.74
	1982(6)	442 414 - 469	.17 .12 - .21	1150.9 904.0 - 1397.8	.99 .68 - 1.29
>500	1981(4)	545 506 - 585	.06 -.06 - .17	2468.6 1710.1 - 3227.1	1.31 -4.26 - 6.88
	1982	525 515 - 534	.02 -.02 - .07	2025.0 1792.5 - 2257.5	-.085 -2.20 - 2.03

greater during 1980 than other years, when hydrilla coverage was in excess of 90%, growth was lower than that reported for comparable sized fish in other Florida lakes (Shireman and Maceina 1982). Food habitat analysis revealed a shift from a diet consisting primarily of small vegetation dwelling fish in 1980 to a diet of shrimp and invertebrates in 1982. Blocknet data collected in October 1982 also showed a near elimination of small vegetation dwelling fish (golden topminnows, bluespotted sunfish and bluefin killifish) and bluegills <100 mm. Lawrence (1957) found bass <250 mm could not consume bluegill >80 mm. Because adequate piscivorous prey were not available for the large population of 151-250 mm bass in Lake Pearl, reduced growth rates occurred. Population estimates (Table 73) for 1982 were significantly greater than previous study years for this size group of bass due to extremely high survival of YOY fish in 1981 when hydrilla infestation was great enough to provide both refuge from predation and a large invertebrate prey base.

Bass 251-350 mm represent fish that have just entered the harvestable size group. Confidence intervals for all years did overlap, indicating a lack of significance among years, but when mean total length and weight were examined a trend towards increasing size was evident (Table 74). Bass collected during 1982, following the elimination of hydrilla, were larger. Confidence intervals for mean gm/day growth for this size group revealed negative lower bounds, which is indicative of extremely variable as well as reduced overall population growth. The lack of a large increase in growth in 1982 with submersed vegetation elimination is due to a lack of adequate sized forage. The 251-350 mm bass can only utilize bluegills <115 mm (Lawrence 1957). These bass, therefore, are competing with the smaller size group for the limited forage base. Although there is a trend to improved growth in 1982, in both mm/day and gm/day, growth rates are still well below previous values cited as good growth rates for Florida bass (Crumpton and Smith 1975; Shireman and Maceina 1982).

Table 73. Population estimate total number and confidence limits (a = .05) by size group for each sample period based on the Schnabel method.

				SIZE GROUP									
		Hydrilla		<150	151 - 250			251-350			350		
Year	Month	% cover	% vol.	Population estimate	Population estimate (N)	Lower Limit	Upper Limit	Population estimate	Lower Limit	Upper Limit	Population estimate	Lower Limit	Upper Limit
1978	October			2064									
1979	June							1216	410		144	71	
	October	97	80					2022	847		189	99	1985
1980	February							1073	633	3497	166	103	425
	May	94	47		697	285		1202	885	1872	252	166	521
	August	92	69		1775	731		2138	1662	3135	248	168	470
	October	97	80	2976	2050	1030	205,000	1856	1459	2549	282	194	517
	December	96	64		1106	693	2744	1759	1417	2318	289	205	492
1981	February	93	47		1041	724	2374	1577	1321	1954	294	219	445
	June	93	67		1401	994	2368	1129	982	1327	300	227	442
	October	89	38	6744	2086	1494	3452	1212	1059	1417	325	250	465
1982	February	74	38		2409	1770	3770	1231	1082	1427	324	258	434
	June				2851	2428	3452	1320	1235	1418	356	318	405
	October			144									
	November	0	0		3137	2683	3775	1352	1266	1451	364	300	465

*<150 estimate by length frequency

Table 74. Growth increment of the 1978, 1979, 1980, 1981 and 1982 year classes of largemouth bass in Lake Pearl.

Year Class	Date	Number	Size Range mm/gm	Mean length ± 95% C.I.	Growth mm/day	Mean weight ± 95% C.I.	Growth gm/day	Number of days	Calculated Age I Length (TLmm)
1978	2-14-79	56	102-172 10.5-55.9	132 ± 4.1		24.9 ± 2.61			159
	6-20-79	44	170-225 52.7-135.5	193 ± 4.9	0.60	87.2 ± 7.13	0.61	103	
1979	6-20-79	82	38-96 .7-11.6	68 ± 3.6		4.4 ± .60			137
	10-16-79	29	96-148 5.3-38.0	115 ± 5.9	0.39	16.5 ± 2.53	0.10	118	
	2-5-80	54	87-158 6.7-41.9	122 ± 6.0	0.06	19.5 ± 2.93	0.03	112	
	5-28-80		126-199 17.8-89.9	154 ± 4.2	0.28	42.7 ± 4.21	0.21	113	
1980	5-28-80	50	41-73 .6-4.8	54 ± 2.4		2.9 ± .38			146
	10-28-80		91-148 6.3-33.3	120 ± 4.8	0.43	18.9 ± 2.19	0.11	153	
	2-16-81	73	87-192 7.3-74.2	134 ± 6.5	0.13	29.3 ± 4.26	0.10	110	
	6-01-81		125-225 22.9-156.0	163 ± 5.8	0.28	53.9 ± 6.18	0.23	105	
	10-29-80	107	151-249 40.8-163.2	202 ± 3.7	0.26	89.5 ± 5.22	0.24	150	
1981	6-01-81	28	37-84 .7-8.8	47 ± 3.9		1.7 ± .61			132
	10-29-81	47	74-136 6.1-29.8	96 ± 4.7	0.33	11.6 ± 1.81	0.07	150	
	2-16-82	54	93-174 8.7-52.3	117 ± 3.8	0.19	21.3 ± 1.34	0.09	109	

Table 74. Continued.

Year Class	Date	Number	Size Range mm/gm	Mean length ± 95% C.I.	Growth mm/day	Mean weight ± 95% C.I.	Growth gm/day	Number of days	Calculated Age I Length (TL mm)
	6-02-82	52	117-194 16.3-81.4	142 ± 5.4	0.24	31.9 ± 4.33	0.10	106	
	11-07-82	30	153-221 35.3-110.4	195 ± 3.3	0.33	75.3 ± 4.07	0.27	160	
1982	11-07-82	16	110-147 14.7-34.9	130 ± 3.0		24.2 ± 1.67			

Harvestable largemouth bass 351-500 mm represent both male and female harvestable fish. Lake Pearl bass data coupled with data from previous studies conducted by personnel from the Center for Aquatic Weeds, indicates that male Florida largemouth bass rarely exceed 500 mm TL. Growth data from tagged fish within this size group did reveal significant growth increases once hydrilla was eliminated in 1982, indicating these fish were large enough to utilize the remainder of the piscivorous prey base within Lake Pearl. Mean mm/day and gm/day increases in 1982 for bass 351-500 were comparable to data cited by Crumpton and Smith (1975) as average to good growth rates for Florida bass. This is the only study year in which growth rates have approached previous literature values. Growth rates in 1980 and 1981 were extremely variable, with negative lower bounds on all confidence intervals, indicating little to no growth (Table 74). Savino and Stein (1982) found that bass could not efficiently forage in tank studies when artificial stem density approached levels found within hydrilla mats. Our tagging data substantiates our findings that extremely reduced growth rates occur in years when hydrilla is present.

Bass >500 mm represent the population of large female Florida bass. The low, variable growth rates present in 1981 and 1982 are characteristic of fish that have reached the apex of their growth curve (Table 74).

Growth rates of YOY bass in Lake Pearl were calculated from fish collected with electrofishing gear in 1979, 1980, 1981, and 1982. Largemouth bass in Lake Pearl spawned in all study years between February and June. No YOY fish were present in any of the February collections. Individual year classes were distinguished using length frequency data from seasonal electrofishing samples and growth stanzas for all year classes could be followed for at least one year (Table 74). No YOY bass were collected during Summer 1982 collections, but 16 individuals were collected in November.

Bass fry schools were seen prior to the summer collection, and active bass beds were also observed. The lack of fish in the summer sample was due to predation from the large population of bass present in Lake Pearl. The elimination of submersed vegetation in 1982 removed the refuge that YOY fish had utilized to avoid predation.

Seasonal growth rates for all year classes revealed a distinct relationship with temperature. Maximal growth rates occurred during the summer and fall with a reduction occurring during the winter period. First year growth was completed prior to the winter period. Winter temperatures ranged from 9 to 15 C in Lake Pearl with summer temperatures from 25 to 30 C.

First year bass growth in Lake Pearl was lower than that reported in most other studies conducted in Florida. The 1978 year class was 159 mm TL, 1979 was 137 mm TL, 1980 fish attained 146 mm and 1981 fish reached 132 mm. First year growth was back calculated for each year class using the daily growth increments from summer collections. An annual hatching date of April 1 was used for each study year based on visual observations of spawning activity and the presence of bass fry during this time period. Largemouth bass attained first year lengths of 284 mm in Fort Lauderdale (Clugston 1964) and 241 mm in the Florida Everglades (Dineen 1968). Both of these studies were conducted in South Florida where there is no large decline in winter water temperatures and in turn a decrease in growth during the winter. Chew (1974) calculated first year growth for largemouth bass in Lakes Weir and Hollingsworth which had water temperature regimes similar to Lake Pearl. Bass were 154 mm in Lakes Weir and 196 mm in Hollingsworth after one year; he attributed the difference in growth to winter water temperature difference and a larger forage population in Lake Hollingsworth. Lake Pearl bass had lower first year growth for 1979, 1980 and 1981 year classes, but the 1978 class year had growth rates equivalent to Lake Weir fish which was lowest bass growth previously reported in Florida.

The presence of hydrilla in Lake Pearl has not allowed optimum growth rates for YOY bass. The large forage base of small vegetation dwelling fishes and macroinvertebrates within the hydrilla should provide optimum prey for the small bass, but as with the larger size groups of bass, the young fish can not efficiently utilize the forage base. Lake Pearl bass did not attain harvestable size (>250 mm) until their third year which is much longer than that reported in other Florida lakes. During the period from hatch to first winter, the 1982 year class of bass had significantly larger mean lengths and weights than any of the previous study years. Our data in Lake Pearl has revealed that little winter growth occurs; therefore, growth from hatch to first winter in the critical growth period for YOY Florida largemouth bass. They must grow large enough during their first summer to utilize the prey base of YOY fishes that are present during each annual spring spawn as a piscivorous diet is required for bass to attain optimal growth rates. Hydrilla levels started to decline during Winter 1981, but this vegetation reduction occurred after the critical growth period had occurred for the 1981 year class.

Population estimates by size group for bass >150 mm was calculated for each electrofishing sample in Lake Pearl (Table 73). A Schnabel population estimate was used for the multiple census data. Even if a bass lost a tag, it was classified as a recapture because of a recognizable fin clip. Population estimates were not adjusted for recruitment as individual growth data collected from tagged fish >150 mm revealed little recruitment into succeeding size groups. Standing crop estimates of bass <150 mm were calculated from fall blocknet samples conducted annually in Lake Pearl. Bass <150 mm could not be floy tagged because their growth would have been retarded by the presence of the tag. YOY bass populations attained maximal densities in 1981 (6,744) and minimum levels (6) in 1982 (Table 73). The extremely large standing crops of YOY bass in 1979, 1980 and 1981 was attributed to lack of predation because of hydrilla cover and a large invertebrate prey base associated with hydrilla. The tremendous reduction in young bass numbers in 1982 was due to predation by the larger size groups of bass once all submersed vegetation was removed.

Schnabel estimates for fish 151 to 250 mm stabilized during December 1980 at approximately 1100 fish. February 1981 sampling substantiated these results. A standing crop estimate of 50 fish per ha was calculated from the Schnabel estimate. Growth data for young bass in Lake Pearl indicated this size group to be Age I and II. Although confidence intervals for the June 1981 collection overlapped with the December 1980 and February 1981 intervals, the increase of the estimate to approximately 1400 fish reflects the recruitment of the 1980 year class (fish <150 mm) into this size group. Growth increment data for the 1980 year class supports this recruitment hypothesis as the mean fish length was 163 mm in June, while only 134 mm and 120 mm respectively for the February 1981 and December 1980 collections. Population estimates during November 1982 were significantly larger than 1980 and most of 1981. Lake Pearl had 3000 (approximately 125 bass per ha) in the 151 to 250 mm size group.

Estimates for the intermediate size group (251-350 mm) were 1700 or 71 fish per ha by October 1980. Estimates for December 1980 and February 1981 were similar (Table 73). A significant reduction in standing crop (1130 bass) occurred in June 1981 as confidence intervals did not overlap the October and December estimates and were within the lower bound of the February estimate. Fishing mortality (based on personal observation) had not increased on the lake between the February and June collections, but water level decreased 1 m resulting in a 34% reduction in total water volume. A large increase in natural mortality within this size group may have occurred because of decreased water level. Growth and condition of fish in this size group were extremely poor. For this reason, there was no recruitment into the >350 mm size group. Population estimates for 1982 revealed a slight increase in standing crop for the intermediate size group, but no substantial recruitment occurred because of an insufficient forage base for 151-250 mm bass.

Bass >350 mm have had static population levels in Lake Pearl. The Schnabel estimate became stable by May 1980 at approximately 275 individuals or 11 fish and revealed no significant fluctuations until 1982 when the population of larger fish began to increase. In November, the estimate was 364 fish >350 mm suggesting some recruitment from the smaller size group.

The standing crop of harvestable bass (>250 mm) by November 1982 was 1650 fish, but as in previous study years, the fish were relatively small with 81% of the fish in the 251 to 350 mm size group. Improvement in growth rates in this size group of fish may occur during 1983 as the prey population becomes available. A reduction in total number of harvestable fish will probably occur now that hydrilla has been eliminated in Lake Pearl, but the population will be characterized by larger fish. We predict the harvestable bass population in Lake Pearl will be characteristic of a good sportfish population rather than one skewed to just barely harvestable fish.

Creel Data

Orange Lake

A non-uniform probability type creel survey designed by North Carolina State University was conducted on Orange Lake and Lake Lochloosa. This type of survey was conducted so that our creel data was comparable to prior creel information obtained by the Florida Game and Fresh Water Fish Commission for Florida waters. The creel consisted of

8, 2-week periods during spring sampling and six, 2-week periods during fall sampling. Five creel days per period were randomly selected; one sample day was a weekend day during each period. The lakes were divided into four regions, each area was creeled separately for one hour out of the 4-hour creel day. Each creel day was divided into morning, midday or afternoon time periods. The probability of each time of day sampled was based on prior data collected by the Florida Game and Fresh Water Fish Commission.

During the creel of each area, as many fishermen as possible were interviewed. The number of fishermen per boat, species sought after, total angling effort and number of fish caught were recorded. The geographical area of the fishermen's home was also determined. People from Alachua and Marion counties were considered resident anglers and individuals from other counties and non-Florida residents were designated nonresident anglers.

Center for Aquatic Weeds personnel collected data during 1979 and 1982; all other years were sampled by Florida Game and Fresh Water Fish Commission personnel. Data analysis was performed by North Carolina State University.

Monetary value of the recreational fishery was assessed based on data generated by Babcock (1975). He evaluated the capital outlay spent on the sport fishery for Lake Jackson, Florida. Local anglers spent $2.71 per fishing hour, whereas non-local anglers spent $5.86 per hour because of increased travel and food expenses. Both of these values are conservative due to inflation and increased costs of services and equipment since 1975.

Maximum fishing pressure on Orange Lake occurs annually during the spring spawning periods. The fishery could be characterized as primarily consisting of local anglers fishing for largemouth bass. The lake received considerable fishing pressure during the study period.

The encroachment of hydrilla has dramatically altered fishing pressure within the lake. A comparison of three fall creels (Table 75 and 76) revealed an 86% reduction in fishing pressure and a 90% decrease in revenues from the recreational fishery during 1977 when the hydrilla infestation was widespread. Hydrilla during the fall period was surface matted; therefore, angler accessibility is limited. Hydrilla infestation also caused a dramatic reduction in non-resident angler use of the lake during Fall 1977. During 1978 and 1979, non-residents comprised 37% of the fishermen, while in 1977 they comprised only 3% of the anglers. The presence of dense hydrilla also caused fishermen to change their fishing habits and species selection. Largemouth bass fishing made up 87% of the angling hours during 1977, as compared to 47% in 1978 and 70% in 1979. Bluegill and redear angling pressure in Orange Lake is usually directed to the maidencane and spatterdock communities. During 1977 these habitats were completely vegetated with hydrilla making angling impossible. The pursuit of black crappie occurs in open water, therefore, total coverage of the lake with hydrilla in 1977 eliminated this fishery. Catch/hour of all species except black crappie was greatest during Fall 1977.

Comparison of spring creel data also revealed shifts in angling habits due to the presence of hydrilla. Only during Spring 1982 creel was hydrilla prevalent within the spatterdock-maidencance communities. Its presence within the community caused non-largemouth bass anglers to shift away from the bluegill-redear fishery to black crappie. Open water areas were present during Spring 1982 allowing people to fish for crappie, while hydrilla in the littoral region prevented many people from gaining access to the bream fishery. Although hydrilla was not present in Spring 1978, there was still a large decrease in angling pressure due to poor fishing the previous year. Fishermen, apparently, had not become aware of the hydrilla decrease in 1978. The number of fishermen dramatically increased in

Table 75. Total effort, harvest, success (fish/hr) and exploitation (number/ha removed) for largemouth bass, bluegill, redear and black crappie in Orange Lake, Florida.

Species	Spring 1974	Spring 1978	Spring 1979	Spring 1982	Fall 1977	Fall 1978	Fall 1979
Largemouth bass							
Total hours	49521	26818	69058	40650	6164	23047	38392
% of total	42%	31%	46%	37%	75%	47%	70%
Total numbers	13627	10644	16703	16198	2024	9851	12934
% of total	12%	9%	16%	11%	63%	22%	35%
Fish/hr	0.29	0.32	0.23	.40	0.98	0.44	0.31
Number/ha removed	2.7	2.1	3.2	3.2	0.4	1.9	2.5
Bluegill - Redear							
Total hours	37891	34661	55944	22823	557	8758	9062
% of total	32%	40%	37%	21%	7%	18%	16%
Total numbers	67201	80065	77198	16915	1720	14505	17404
% of total	59%	68%	73%	12%	18%	32%	47%
Fish/hr	1.77	2.31	1.38	.74	3.08	1.66	1.92
Number/ha removed	13.1	15.8	15.0	3.3	0.3	2.8	3.4
Black crappie							
Total hours	19101	24309	26721	46388	331	17559	7618
% of total	16%	28%	18%	42%	4%	36%	14%
Total numbers	17802	23632	11723	109977	273	14126	6317
% of total	16%	20%	11%	77%	3%	32%	17%
Fish/hr	0.93	0.97	0.43	2.37	0.82	0.80	0.82
Number/ha removed	3.5	4.6	2.3	21.7	0.1	2.7	1.2

Table 76. Total effort, harvest, success (fish/hr), exploitation (number/ha removed), percentage angler breakdown and monetary values for Orange Lake, Florida.

	Spring				Fall		
	1974	1978	1979	1982	1977	1978	1979
Total effort	106513	857888	151725	109862	7052	49364	55073
Total numbers	98638	114341	105929	143111	8066	38482	35182
Fish/hr	.93	1.33	.70	1.30	1.14	.78	.64
Number/ha removed	22.0	23.9	22.2	29.9	2.62	8.33	7.36
% local anglers[a]		54	51	51	97	63	62
% non-local anglers[b]		46	49	49	3	37	38
Monetary value resident		125609	209810	151920	18547	84323	92582
Monetary value non-resident		231252	435663	315458	1240	83437	122635
Total monetary value		356861	645473	467378	19787	167760	215217

[a] Local anglers represent fishermen from Alachua and Marion counties, Florida.

[b] Non-local anglers represent fishermen from other counties within the state and non-resident fishermen.

1979. The increase of hydrilla in 1981 again resulted in decreased angling pressure during Spring 1982.

The calculated monetary values of the fishing, although conservative in this report, do reflect the potential loss of income as a result of hydrilla. If 1979 values are used as baseline, a 45% reduction in monetary value occurred in Spring 1978 and a 38% reduction in Spring 1982. Although the fall fishery provides only 30% of the revenue when the two seasons are compared, it still contributes almost a quarter million dollars to the local economy. Hydrilla, during its peak growth in 1977, indirectly reduced the income derived from sportfishing by 90%. The presence of hydrilla in Orange Lake did not decrease fishery success, and resulted in a substantial increase in largemouth bass catch rates. However, dramatic reductions in total angler usage, occurred which resulted in reduced revenue. Once hydrilla covered the entire lake, fishing was limited to individuals who lived within close proximity of Orange Lake. Creel census data demonstrate that dramatic reduction in sport fishing occurred as a result of hydrilla infestation. The ultimate result was the closure of several fish camps during 1977.

CONCLUSIONS

Orange Lake, Lake Pearl and Welaka Pond data indicate that hydrilla can rapidly colonize both the littoral and pelagic lake regions under optimal limnolcgical conditions. In shallow water systems, such as Lake Pearl, this can eliminate the ecotone between open water and vegetated areas. Dense vegetation, therefore, causes alterations in water quality, and native plant and animal communities. Whether these changes are good, bad, or indifferent depends upon the criteria used to judge the quality of the lake by various user groups.

Our study, like many others, demonstrates that aquatic macrophytes may alter water quality. In Lake Pearl, where macrophyte abundance was initially high, we observed a reduction in average pH, and an increase in bicarbonate, specific conductivity, calcium, magnesium, potassium, total nitrogen, total phosphorus, color, turbidity, and chlorophyll a, which coincided with a major reduction in submersed macrophyte abundance. No statistically significant effects of macrophytes on water quality, however, could be demonstrated in Orange Lake or the Welaka ponds. With the exception of chlorophyll a which was directly influenced by macrophyte abundance, water quality changes in Lake Pearl were caused primarily by hydrologic changes. This study demonstrates that overall lake water quality changes will occur only if macrophyte abundance is high and generally above levels acceptable to user groups. Alterations in water quality, resulting from aquatic plant management programs, will generally be short term and lakes will return to their limnological potential based on material loading rates, lake mean depth, sedimentation rates and hydrologic flushing rates. Overall, lake hydrology and change in land use practices within the watershed have greater long term impacts on water quality than invasion by macrophytes or their control.

In Orange Lake, Lake Pearl and Welaka ponds, native emergent and floating leafed plants did not undergo any reduction in coverage or frequency of occurrence as hydrilla expanded into these vegetation communities. Changes in water level seemed to affect these communities more than the abundance of hydrilla. Hydrilla, however, can eliminate native submersed vegetation. This is apparently caused by its ability to utilize free CO_2 at lower light intensities than native submersed vegetation. The growth form of hydrilla which is characterized by dense continuous surface mats, can also limit light penetration, which also inhibits the growth of other submersed species. With increases in hydrilla, there is a trend toward reduced algal cell numbers. This trend is reversed when hydrilla abundance is reduced. In Lake Pearl, following the major reduction of macrophytes, there was a shift in dominance from bluegreen to green algae. Similar phytoplankton changes were observed in Orange Lake as bluegreen algae became dominant with an increase in hydrilla. Whether these changes in algal community composition are directly related to hydrilla abundance, or indirectly to changes in other factors such as the abundance of specific plant nutrients is unknown.

In Lake Pearl, a decline in total benthic macroinvertebrates and littoral zooplankton, with a simultaneous increase in pelagic zooplankton, occurred as the hydrilla volume decreased. In Orange Lake, the greatest number and variety of invertebrates were collected from the vegetated regions, while the fewest were collected from the nonvegetated lake region. Among vegetative habitats, spatterdock supported the greatest number and variety of zooplankton species and the largest number of benthic macroinvertebrate taxa; whereas hydrilla supported a significantly greater number of benthic macroinvertebrates. Our results for these lakes indicate that both the amount and type of aquatic vegetation influenced the abundance and species of invertebrates collected. Within the Welaka ponds, zooplankton and benthic macroinvertebrates populations were not significantly different among treatments or among vegetation levels.

In Orange Lake and Lake Pearl, we found that large increases in fish species present, total numbers, and biomass occurred when hydrilla coverage exceeded 60%. The increase in the number of species present was the result of increases in the population densities of small littoral fishes such as bluefin killifish, golden topminnows and bluespotted sunfish. As hydrilla expands, the abundance of these littoral fishes which generally occur only in low numbers, increases. At high hydrilla levels, these fish become a major biotic component. Sportfish populations undergo shifts in length frequency distributions, with the distributions becoming skewed toward small to intermediate sized individuals. Under these conditions, there is little or no growth and very few fish recruit into larger size classes which causes an overall stunting of the sportfish populations. There also may be a shift in predator dominance. For example, in Orange Lake, chain pickerel, a fish not sought after by the majority of sportfishermen and direct competitor of the preferred sportfish (largemouth bass), underwent large increases in abundance due to the establishment of their preferred habitat (vegetation). As hydrilla is removed from the system, these trends are reversed. The number and biomass of littoral species which are dependent on submerged vegetation for food and shelter are reduced but not eliminated.

YOY and intermediate sized sportfish numbers are reduced as small fish are no longer protected from predation by dense vegetation cover. Concomittantly, there is a reduction in total fish biomass and sportfish biomass, but the average weight of individual sportfish increases. These changes in population occur rapidly, however, 3-5 years are probably necessary for fish populations to stabilize after hydrilla is removed from the system.

Integrated plant management utilizing grass carp and herbicides, was not successful for managing aquatic plants to prescribed levels in Lake Pearl. Herbicide treatments were required frequently and control was not always precise. Introduction of grass carp did not control regrowth in treated areas, thus herbicide usage in the treatment area was not reduced. In the untreated area, grass carp reduced hydrilla only in small areas until stocking rates reached 16 fish/ha. At this stocking rate, measurable changes in hydrilla levels were recorded. This stocking rate, however, eliminated all hydrilla from the system. This suggests that unless very intensive grass carp management, as done in the Welaka ponds, is utilized, it is unlikely that submersed vegetation can be managed for and maintained at a specific level in larger systems with grass carp. Floating leafed plants, however, increased in Lake Pearl, suggesting that under appropriate conditions, high grass carp numbers will not necessarily reduce or eliminate floating leafed vegetation. However, the long term impact of grass carp on this type of vegetation is unknown.

During our study, we were not able to definitively demonstrate any direct impact of herbicides or grass carp on water quality or invertebrates and fish populations, however, our data clearly demonstrate that biological and water quality changes occur as vegetation abundance is altered by natural and anthropogenic factors. This suggests that the potential environmental impact of various aquatic plant management programs will be determined more by the amount of vegetation controlled than by the control method used whether it be herbicides (used according to label instructions), grass carp, or mechanical harvesting.

Research Recommendations

Shireman et al. (1982), in a comprehensive review, examined and summarized the literature on the impact of aquatic plants and their management techniques on the aquatic environment. In that document, the authors posed a series of questions as research topics. Although the present research answered and provided insight into some of these topics, many of the questions posed remain valid and the reader should refer to Shireman et al. (1982).

Several additional research projects which we feel are important are listed here.

1). Our data clearly indicate that grass carp can eradicate submersed vegetation from lake ecosystems and Shireman (1982) has shown it can be done at a fraction of the cost of herbicide methods. The long term impact of complete removal of submersed vegetation on the aquatic environment is not known and remains a major point of contention.

Based on our data, we believe that at least 3-5 years of study will be necessary after macrophyte removal to determine the ultimate impact of vegetation removal because many fish species are long lived and water quality is significantly influenced by long term lake hydrology. Consequently, research dollars are needed for continuation of long term ongoing grass carp research projects where aquatic vegetation has been eradicated. If aquatic vegetation is not necessary for the functioning of the ecosystem, grass carp could be used as a cost-effective biological control for aquatic weeds.

2). A continua of lake types and biological communities exist in lakes in the United States. In the last decade, limnologists and fishery biologists have developed empirical models based on regression analysis between important state variables to describe parts of these continua. These empirical relationships have become increasingly important to researchers and those charged with managing lakes, because these models provide quantitative predictions of changes in important variables given changes in other variables and provide the basis for the development of further hypothesis concerning the functioning of lake ecosystems. Most empirical relationships, however, have concentrated on a prediction of parameters associated with phytoplankton or fish communities given measurements of nutrient supply or whole lake characteristics. No empirical models have been developed to predict the impact of different levels of aquatic macrophytes on lake limnology and fisheries. Consequently, it is presently difficult to predict the impact of aquatic plant management on the limnology of lakes of different trophic status.

A survey of a large number of lakes, ranging from oligotrophic to eutrophic should be conducted. Quantitative data pertaining to nutrient loading rates, in lake nutrient concentrations, chlorophyll a concentrations, zooplankton and fish biomass, and macrophyte abundance should be collected and incorporated into empirical models which can then be used to predict changes in the biological coenosis. This type of information would permit a quantitative environmental assessment of the impact of different lake management strategies on lake ecosystems and allow the development of rational cost-benefit analyses.

3). Studies in Russia (Veriqin 1978), Poland (Opuszynski, 1981), and Israel (Leventer 1979), have demonstrated that icthyofauna reconstruction and management has the potential to alleviate many of the problems associated with the eutrophication of water bodies. In the United States, we currently rely on engineering techniques such as nutrient diversion and nutrient limitation techniques which are extremely costly. Although some research has been conducted to test the feasibility of manipulating zooplankton populations to control algae, there have been no major attempts, other than the use of grass carp, to use fishery management techniques to counteract the eutrophication process in this country. Research is needed to test the hypothesis concerning ichthyofauna reconstruction and management developed by scientists in other parts of the world. Native and introduced fish species should be tested and management evaluations made. If this research is successful, considerable monetary savings could be made as well as enhancing both commercial and sportfisheries values.

4). Nutrient abatement has been suggested as a component control procedure in integrated aquatic weed management. This may be feasible where control of nutrient inputs is possible, such as oligotrophic sandhill lakes in Florida and other regions which have been impacted by point source nutrient inputs. Although laboratory studies related to the nutritional requirements of aquatic macrophytes is extensive, little is understood about the relationships between aquatic weeds and nutrients in water and hydrosoil under natural conditions. These questions must be addressed in order to determine the applicability of nutrient abatement as a means of aquatic weed management.

5). With the rising cost of chemical treatment and increased environmental concern over the use of agricultural chemicals, alternative weed control procedures must be continuosly evaluated. Mechanical weed control is expensive but is a viable aquatic weed control procedure in some situations. In order to predict the results and make recommendations for application of mechanical harvesting, studies are needed to determine the most effective timing of mechanical harvesting of selected aquatic weeds, determine regrowth rates of selected weeds in different trophic state aquatic habitats, and determine the effects of repeated harvesting on regrowth rates and water chemistry.

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